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Review

Evaluating the use of electromyography in UK and European gait laboratories for the assessment of cerebral palsy and other neurological and musculoskeletal conditions

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ABSTRACT

Background: Electromyography (EMG) can estimate the magnitude and timing of muscle activation during walking in those with gait disorders. Despite the potential of EMG use in assessment and clinical decision-making, there are reports of declining use of EMG within gait laboratories. Technical and educational barriers to EMG usage in clinics in Italy were recently suggested.
Research question: What is the current EMG practice and associated knowledge and barriers to EMG usage in UK and European clinical gait labs?
Methods: Semi-structured interviews were conducted online with 16 participants recruited from 13 gait laboratories across the UK and wider Europe, 11 participants used EMG routinely in clinical service and five did not. Participants held various professions including physiotherapists, clinical scientists, a lab manager, biomechanist, orthopaedic surgeon and a biomedical engineer. Interviews were transcribed and analysed using reflexive thematic analysis.
Results: EMG training was often completed in-house informally by colleagues. Findings show EMG was currently used for assessing muscle activation timings, spasticity, co-contraction in patients and often used as a confirmatory tool. Challenges of using EMG included: justifying the effort, distinguishing true deviations from the norm, capacity to collect good quality data and feasibility with a given patient.
Significance: The challenge of interpreting EMG signals, patient readiness and time requirements were consistent between the gait labs reflecting previous reports from Italy. There were also large variations in types of EMG training and education in agreement with previous findings. In contrast to previous findings, cost was not considered important within this study.
Conclusion: For EMG to be more widely and routinely used, the perceived effort of staff and patients would need to be justified by a clear link to the treatment planning and decision-making through further published evidence and training.

1. Introduction

Clinical gait analysis provides an objective assessment of the walking pattern of patients, such as those with cerebral palsy (CP), to inform diagnosis, surgical decision-making and treatment. Three-dimensional clinical gait analysis has been shown to be effective in changing and reinforcing treatment decision, increasing agreement among clinicians and improving patient outcomes [1–3]. Electromyography (EMG) can be used as part of a clinical gait analysis by providing an indication of muscle activation during walking. EMG data can be used in a clinical setting to determine the timing of muscle activity and to establish the presence of spasticity, paresis and the co-contractions of the muscles which may be contributing to impaired movement patterns [4–6]. Previous studies indicated that EMG is a reliable method when evaluating CP patients dynamically during gait [7], and that using EMG techniques can contribute to the improvement of treatment management and

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interventions processes in children with CP [8]. Moreover, a survey of gait lab clinicians found that 90 % of participants thought that EMG information was 'at least somewhat helpful' and 79 % considered it to be 'at least somewhat reliable' in the context of assessing CP patients [9].

Despite the potential utility of EMG in the clinical decision-making process for complex surgical interventions and the evaluation of their outcomes, there appears to be a decline in use during routine clinical practice [4]. Barriers to the clinical use of EMG may be cultural, educational, technical, economic and administrative [10,11]. A study in Italy found that only 25 % of the 28 clinicians who participated in a survey used EMG in clinical practice, however, the vast majority expressed their willingness to use EMG to improve their neurological assessments [12]. The top barriers to EMG usage were difficultly of data interpretation, insufficient education, cost of EMG equipment, time constraints and lack to evidence on the role of EMG's contribution to clinical decision-making. However, this study only gained responses from a single centre, therefore did not explore responses from a range of labs with various clinical practices. In the UK and Ireland, approximately half of the labs accredited with Clinical Movement Analysis Society (CMAS) currently use EMG according to their 'statement of purpose' [13]. The aim of this study was to establish the current EMG practice in European clinical gait labs and associated challenges to EMG usage, as well as the associated knowledge and beliefs of the gait lab staff. The findings of this study could be used to inform future training, improve EMG quality assurance processes and work towards using EMG to its full potential in clinical practice.

2. Methodology

To evaluate the use of EMG, a phenomenological approach was taken using online semi-structured interviews. Ethical Approval was received from Liverpool Hope University and participants provided consent electronically prior to the interview including consent for the interview to be recorded.

2.1. Participants

Sixteen participants were recruited from the European Society for Movement Analysis in Adults and Children (ESMAC) and CMAS communities via e-mail. Participants were eligible for the study if they were currently working in an affiliated gait lab providing a clinical gait service. To gain a variety of perspectives, the participants held various professions (Table 1).

2.2. Procedure

Data was collected through online interviews on Zoom (Zoom Video Communications, Inc., San Jose, California) or MSTeams (Microsoft Corporation, Redmond, Washington), with one interview conducted face-to-face and online concurrently. Each participant was allocated a code to protect their anonymity, and names were removed within Zoom and MSTeams during the interviews, any identifiable information such as laboratory name or co-worker names were also removed from the transcript. The interviews were conducted by either both authors (J.R and H.S) or individually with (J.R) or (H.S). The interviews took place between February 2023 and May 2023. The average duration of the interviews was 32:49 ± 11:53 minutes.

Building upon the outcomes of the study by Cappellini et al. [12], the open-ended questions asked within the interviews are outlined in (Table 2). The interviews followed a semi-structured approach therefore the questions were not always asked in a specific sequence and were dependant on participant responses. Additionally, questions 4–8 were not relevant to those currently not using EMG for clinical practice.

2.3. Data Analysis

Audio-recordings from the interview were transcribed verbatim using the Zoom and MSTeams automatic transcription, any errors were corrected by manual editing. The transcripts were analysed using reflexive thematic analysis [14]. This approach was chosen because it involves owning the perspectives of the researcher and recognises that themes are generated by the researcher and are mediated by their own skills and experiences [15,16]. The familiarisation and coding stage involved rereading the transcripts and highlighting keywords and phrases as codes. These stages were conducted by author J.R. who has a background in sport and clinical biomechanics and has experience with surface and fine-wire EMG data through PhD and postdoctoral work. Additionally, J.R. has previously conducted thematic analysis of the footwear needs of active older adults. Initial themes were then generated by visualising codes in mind maps. Themes were developed and refined through discussion with all authors. Author H.S. also has a background in sport and clinical biomechanics with expertise in gait and is a member of the CMAS standards committee. H.S. reviewed the coded transcripts to quantify codes and establish any missing useful insights from the initial coding and theme development. Author C.S. is a clinical engineer and manager of a CMAS accredited laboratory which routinely uses EMG. C.S. has over 20 years' experience in gait analysis and is one of the founding members of CMAS.

3. Results

3.1. Participant characteristics

A total of 16 participants were recruited from 13 gait labs (9 UK and Ireland CMAS affiliated and four European ESMAC affiliated gait labs including three labs from Germany and one from Greece). In three of the gait labs, two members agreed to be interviewed but were from various professions. Of the 16 participants, 11 currently used EMG routinely in their clinical service and five did not (Table 1), this meant 10 labs were using EMG and three labs were not. Participant professions included six physiotherapists, six clinical scientists, one lab manager, one biomedical engineer, one biomechanist and one orthopaedic surgeon.

3.2. Knowledge and Training

Across participants the years of EMG experience ranged from 0 to 30 years. Most participants (n = 10) had received 'in-house' EMG training, and half of the participants (n = 8) had covered some EMG training within a gait analysis course led by relevant gait analysis societies (ESMAC, CMAS, GCMAS or GAMMA) (Table 1), one participant who does not currently use EMG, had had no previous EMG training.

3.3. EMG data collection and interpretation

Of the participants using EMG (n = 11) all used surface EMG and only one participant currently used fine-wire EMG. Another gait lab had previously used fine-wire EMG however stopped due to lack of trained personnel "we did stop doing fine-wire because the physio who was trained in that left, retired, and we haven't got anyone that's taken over" (P3).

Quality assurance for data collection varied across labs, participants that were directly involved in placing EMG sensors (n = 7) stated that they followed the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) guidelines [17], although one participant questioned the guidelines applicability to the CP muscle bulk, when talking about SENIAM guidelines mentioned "they're loosely based on that, but not strictly...I think there is some clinical judgment that has to come in as well, to have like a very clear protocol of placement" (P3). Four participants mentioned that they do repeatability testing with one participant noting the lack of advice on the best way to perform

Table 1
Participant job roles, clinical activities and training and experience.

	Job Role	Location (UK or Europe)	Main Clinical Activities	EMG in current practice	Years with EMG experience	Training
P1	Clinical Scientist	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Spinal injuries Stroke Orthotics Prosthetics	Yes	12	Research In-house
P2	Physiotherapist	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Spinal injuries Stroke Orthotics Prosthetics Multiple Sclerosis	Yes	17	In-house No formal training
P3	Clinical Scientist	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Spinal injuries Stroke Orthotics Prosthetics Upper Limb	Yes	28	In-house Advanced EMG course/ seminar Gait analysis course (ESMAC/ CMAS)
P4	Research Physiotherapist	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Stroke Orthotics Prosthetics Upper Limb	Yes	8	PhD Research Gait analysis course (ESMAC/ CMAS) In-house
P5	Clinical Scientist	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Spinal injuries Stroke Orthotics Prosthetics	No	*Not explicitly stated*	University
P6	Clinical Scientist	Europe (Germany)	Adults Trauma Prosthetics Upper extremity Neuromuscular disorders	Yes	11	PhD research Advanced EMG course/ seminar In-house
P7	Clinical Scientist	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Spinal injuries Stroke Orthotics Prosthetics Functional Electrical Stimulation service	No	< 1	CMAS member visits Gait analysis course (ESMAC/ CMAS) Manufacturer installation training
P8	Lab Manager	Europe (Germany)	Adults and children Neuromuscular disorders Orthopaedics Prosthetics Orthotics	Yes	22	Gait analysis course (ESMAC/ GAMMA) In-house
P9	Physiotherapist	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics	No	*Not explicitly stated*	Intense 3-week EMG training

(*continued on next page*)

Table 1 (*continued*)

	Job Role	Location (UK or Europe)	Main Clinical Activities	EMG in current practice	Years with EMG experience	Training
			Spinal injuries Stroke Orthotics Prosthetics			
P10	Biomedical Engineer	Europe (Germany)	Children Cerebral palsy Neuromuscular disorders Orthopaedics	Yes	11	University In-house training Manufacturer installation training
P11	Physiotherapist	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Spinal injuries Stroke Orthotics Prosthetics Sports injuries Idiopathic toe walking	Yes	12	PhD research Gait analysis course (ESMAC/ CMAS/ Gillette) Manufacturer installation training
P12	Physiotherapist / Lab manager	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Spinal injuries Stroke Orthotics Prosthetics Sports injuries Functional Electrical Stimulation service	Yes	23	Gait analysis courses (ESMAC/ CMAS) In-house
P13	Biomechanist	Europe (Greece)	Adults and children Cerebral palsy Neuromuscular disorders Multiple Sclerosis	Yes	8	University Gait analysis courses (ESMAC) In-house
P14	Orthopaedic Surgeon	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Spinal injuries Stroke Orthotics Prosthetics Sports injuries Functional Electrical Stimulation service Upper extremity	Yes	30	Gait analysis courses (ESMAC/ CMAS) In-house
P15	Physiotherapist	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Spinal injuries Stroke Orthotics Prosthetics Idiopathic toe walking	No	0	None
P16	Clinical Scientist	UK	Adults and children Cerebral palsy Neuromuscular disorders Foot disorders Orthopaedics Spinal injuries Stroke Orthotics Prosthetics Idiopathic toe walking	No	4	University In-house

repeatability checks “from the repeatability side I don’t think there’s a lot of advice on that” (P1).

All EMG users (n = 11) stated that they use the raw EMG data and focus on the muscle activation timings within data interpretation. Most participants (n = 9) interpreted the EMG data through a qualitative assessment, with one lab further quantifying the data using a co-contraction index, and another applying an autoclassification program to quantify timing thresholds (Table 3).

Table 2
Interview Questions.

Question Number	Question	Additional Prompt
Job Role/Occupation		
1	Can you tell us what your occupation/job title is within the gait lab?	
2	Can you tell us about what your role involves and the activities that you complete as part of your role?	
Current Usage		
3	Do you use EMG in your current practice? (if answer is no, go to *'Potential Usage'*)	If not, why is this?
4	What EMG system do you use?	Is this fine wire or surface or both?
5	How often is the EMG system used in relation to patient numbers/testing days?	
6	Which clinical conditions from referrals do you use EMG for?	
7	Which assessments do you currently use EMG for? (e.g. characterising spasticity, muscle fatigue etc.)	What are you looking for within the data, amplitude, timings etc.?
8	How much do you think your current EMG practice contributes to the surgical planning and decision process?	
Potential Usage		
9	Do you think EMG could be useful in treatment and/or decision-making for specific conditions?	What about…?
10	Do you think there is enough evidence that EMG can improve treatment decision-making and/or outcome?	
Knowledge of the EMG system		
11	How confident are you using EMG system to collect data? *If not using:* How confident would you be?	
12	How confident are you at analysing the data?	
13	How confident are you at interpret EMG data for clinical purposes?	
14	How many years have you been using EMG?	Was this trained at university, during the job etc.?
15	Do you regularly attend training/ courses on EMG?	Where is this training held, in-house, conferences etc.?
16	Are all members of the gait team trained on the EMG system or is this specific to individual roles within the gait lab?	
Potential Barriers		
17	Are there any reasons why EMG would not be included in the gait analysis in cases where it could be useful?	
18	Do you consider there to be barriers to the clinical use of EMG?	
19	What do you think would help to overcome the barriers you have suggested?	
Closing		
20	Was there anything else you wanted to add that you didn't have a chance to say, or any questions you'd like to ask us?	

3.4. Themes

The global theme of EMG practice in gait analysis was split into the organising themes of "usage" and "challenges" and further divided into basic themes (Fig. 1). We chose the term "challenges" rather than "barriers" previously used by Cappellini et al. [12] because many of the basic themes were common across laboratories not using EMG, where an issue could be a barrier to implementation, and laboratories using EMG, where basic themes are challenges to overcome. The "usage" theme was split into the basic themes of "activation timing", "spasticity", "confirmation" and "co-contraction". The "challenges" theme was divided into "feasibility with a given patient", "capacity to collect good quality data", "justifying the effort" and "distinguishing true deviations from the norm". Example statements corresponding to each basic theme are presented below.

3.4.1. *Theme 1: Usage*

The percentage of patients where EMG was used ranged from 15 % up to 90–100 % of patients, demonstrating a wide range across the labs that currently use EMG (Table 3). Four labs reportedly used EMG on 80 + % of patients, these labs included EMG on every patient as routine practice except for feasibility or technical issues (highlighted in the challenges theme). For the remaining six labs, the decision to use EMG depended on the clinical condition (e.g. CP, functional electrical stimulation patients, multiple sclerosis or fatigue), the referral question such as suitability for rectus transfer surgery, pre- and post-selective dorsal rhizotomy or if a question was raised during the clinical exam which may warrant further investigation using EMG.

"So clinical conditions, I think it's maybe less so. It's more if the referral questions is looking at surgery, then it tends to be a more, we'll do that [EMG] test" (P1).

"we would routinely use EMG on first visit CP patients…and then we would use the EMG if there was a specific [referral] question associated with muscle activity, but we don't use it on all patients" (P3).

When asked "which assessments do you currently use EMG for?" or "how are you using EMG data?" four basic themes appeared:

3.4.1.1. Activation timing. All participants using EMG ($n = 11$), whether raw or processed, were interested in the profile of activation timing by normalising EMG to % gait cycle, from purely a qualitative perspective. The timing of muscle activation was considered in relation to where activation would be expected in a healthy gait cycle. In one lab ($n = 1$), activation onsets/offsets were quantified with an algorithm.

"We look at the timing first and foremost, and then we look at the amplitude… is it on at the right time, is it off at the right time" (P10).

One participant (P8) stated that the evidence of "late and diminished rectus activity in swing phase" should be a requirement before indicating a rectus transfer.

3.4.1.2. Spasticity. Eight participants considered EMG a useful tool for ruling out or confirming spasticity (Table 3) through observing whether or not there was over-activity in a muscle.

"you're measuring them clinically, and you think you're picking up some spasticity on the couch, then we might use EMG, and that helps inform whether there actually is over-activity" (P3).

3.4.1.3. Co-contraction. Ten participants reported looking at co-contraction, mostly through qualitative assessment although one participant (P14) calculates a co-contraction index. It was suggested EMG was useful for identifying co-contraction, as it may not be detected through the other routine gait analysis tests (kinematics, kinetics, clinical exam). When speaking about EMG usage in a former lab: "co-contraction of muscles and things that are not easily testable by, you know, by just a standard clinical assessment, it, that [EMG] did have useful information" (P16).

3.4.1.4. Confirmation. Electromyography data was used as a confirmation tool ($n = 7$) (Table 3) to supplement other data (kinematics and kinetics) and rarely the primary source of information to influence decision-making.

Table 3
For the participants currently using EMG in clinical practice, the EMG systems used, when EMG is used and how EMG signals are processed and interpreted.

	Fine wire / surface EMG	EMG system used	Approx % of patients where EMG is used	Muscles / subset of muscles measured	Quality Assurance	Data Processing	Data Interpretation	When and how EMG is used
P1	Surface	Delsys wireless	50 %	Gastrocnemius Medial hamstring Peroneus longus Rectus femoris Tibialis anterior Vastus lateralis	SENIAM guidelines Sensor attachment checks Static activation tests	Raw EMG data	Co-contraction Comparison to lab normative dataset Muscle activation timings Qualitative assessment	Botox pre/post op Confirmative tool Surgical referrals / treatments
P2	Surface	Delsys wireless	30 %	Gastrocnemius Medial hamstring Peroneus Rectus femoris Tibialis anterior Vasti (medial/ lateral)	Compare to physical exam 'triple flexion test' SENIAM guidelines Sensor attachment checks Static activation tests Maximal strength test (if possible)	Raw EMG data	Co-contraction Comparison to lab normative dataset Muscle activation timings Qualitative assessment	Fatigue Feedback to the patient (foot drop) Functional Electrical Stimulation (FES) outcomes Muscle lengthening Selective dorsal rhizotomy Tendon / muscle transfers
P3	Surface	Bonita Wireless	25 %	Gastrocnemius Rectus femoris Tibialis anterior	Repeatability testing SENIAM guidelines Static activation tests	Autoclassification program for timing thresholds Normalisation to maximal contraction within the gait cycle. Raw EMG data Rectifying and filtering	Co-contraction Muscle activation timings Qualitative assessment	Botox pre/post op Confirmative tool Diagnostic queries Tendon / muscle transfers Confirmation of / ruling out spasticity
P4	Surface	BTS Bioengineering	25 %	Gastrocnemius Hamstring Rectus femoris Tibialis anterior	Static activation tests	Normalisation to maximal contraction within the gait cycle. Raw EMG data Rectifying and filtering	Co-contraction Muscle activation timings Qualitative assessment	Botox pre/post op Diagnostic queries Selective dorsal rhizotomy Tendon / muscle transfers Confirmation of / ruling out spasticity
P6	Surface	Noraxon desktop DTS	25 %	Biceps brachii Tibialis anterior Triceps Wrist extensors Wrist flexors	SENIAM guidelines	Raw EMG data Rectify and Filtering	Co-contraction Comparison to lab and published normative dataset (lower extremity) Comparison to uninjured limb (upper extremity) Muscle activation timings Qualitative assessment	Diagnostic queries Hyper selective neurectomy (upper extremity) Real-time biofeedback for re-training Confirmation of / ruling out spasticity
P8	Surface	Delsys	80–90 %	Biceps femoris Gastrocnemius Gluteus medius Peroneus longus Rectus femoris Semimembranosus Soleus Tibialis anterior Vastus	Sensor attachment checks	Linear envelope (rectify / smooth) Normalised to 200 % across gait cycle Raw EMG data	Co-contraction Comparison to lab normative dataset Muscle activation timings Qualitative assessment	Confirmative tool Diagnostic queries FES outcomes Tendon / muscle transfers Confirmation of / ruling out spasticity
P10	Surface	Noraxon	90 %+	Biceps femoris Gastrocnemius Rectus femoris Tibialis anterior	Activation amplitude < 100 microvolts noted Sensor attachment checks Static activation tests	Raw EMG data	Comparison to lab and published normative dataset Muscle activation timings Qualitative assessment	Confirmative tool Tendon / muscle transfers Confirmation of / ruling out spasticity
P11	Surface	Delsys wireless	90 %+	Medial gastrocnemius Medial hamstring Rectus femoris Tibialis anterior	Repeatability testing SENIAM guidelines Static activation tests	Linear envelope (rectify / smooth) Raw EMG data	Co-contraction Comparison to published normative dataset Muscle activation timings	Confirmative tool Diagnostic queries Confirmation of / ruling out spasticity

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Table 3 (*continued*)

	Fine wire / surface EMG	EMG system used	Approx % of patients where EMG is used	Muscles / subset of muscles measured	Quality Assurance	Data Processing	Data Interpretation	When and how EMG is used
							Qualitative assessment	
P12	Surface	BTS Bioengineering	15 %	Gastrocnemius Rectus femoris	Repeatability testing SENIAM guidelines Sensor attachment checks	Linear envelope (rectify / smooth) Raw EMG data	Co-contraction Comparison to lab normative dataset Muscle activation timings Qualitative assessment	Botox pre/post op Diagnostic queries FES outcomes Tendon / muscle transfers
P13	Surface	Noraxon	80–90 %	Biceps femoris Medial gastrocnemius Rectus femoris Tibialis anterior	*Not explicitly mentioned*	Raw EMG data	Co-contraction Comparison to lab normative dataset Muscle activation timings Qualitative assessment	Confirmative tool Surgical referrals / treatments
P14	Surface & Fine wire	Delsys	20 %	Flexor hallucis longus (fine wire) Peronei Rectus femoris Tibialis anterior Tibialis posterior (fine wire)	Repeatability testing SENIAM guidelines	Co-contraction index Non-negative matrix factorization / synergy counts Raw EMG data	Co-contraction Comparison to lab normative database Muscle activation timings Qualitative assessment	Botox pre/post op Confirmative tool Knee instability / knee pain Tendon / muscle transfers Selective dorsal rhizotomy Confirmation of / ruling out spasticity

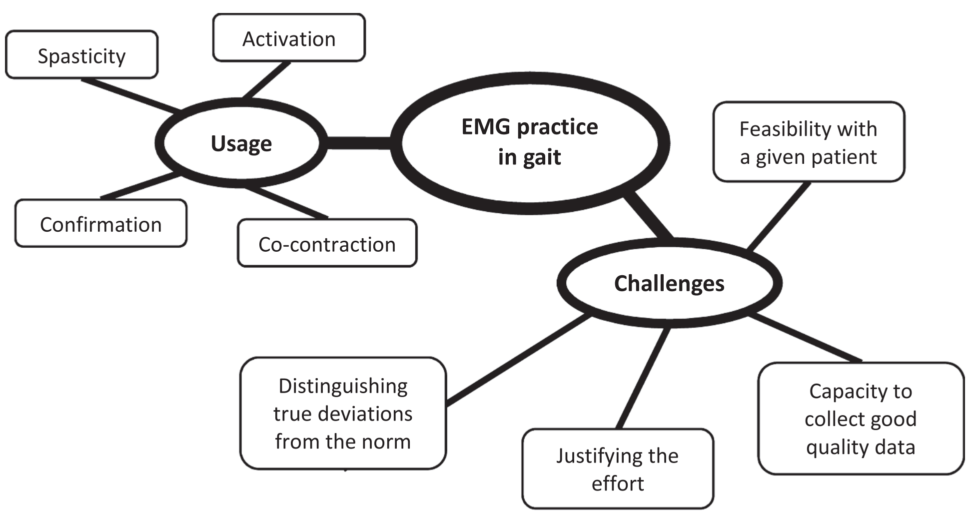

Fig. 1. The global, organising and basic themes of EMG practice in gait analysis.

"it's sort of the thin layer of icing on the cake, but it's not it's not the main meal" (P14).

"that, last bit that we use to convince ourselves that we're interpreting something on the other graphs correctly" (P11).

3.4.2. *Theme 2: Challenges*

3.4.2.1. Feasibility with a given patient. Nine participants who use EMG, and two who don't stated that feasibility with a given patient including difficulties in recording EMG data based on the physical, cognitive and emotional state of the patient was a main challenge. The physical concerns related to a limited amount of space to affix sensors on children ($n = 5$), adipose tissue affecting data quality ($n = 3$), orthoses obstructing where a sensor would typically be placed ($n = 5$) and the discomfort associated with fine-wire electrodes.

Physical concerns included the size of the patient (often children) and space to affix the sensors: "when kids are too small, we just don't have enough space for everything on the skin" (P10).

"no space for the EMG because like, for instance, the patient has an orthosis on" (P6).

Increased adipose tissue also limited EMG data collection: "sometimes we want to do it, and then we do test, and you think, 'oh, actually, this is no good' because the person is actually too fat, and we're not going to get good data" (P2).

However, high adipose was not a great concern across the group, likely due to analysing predominantly paediatric patients:

"The majority of children are, not all of them, but they are quite lean around the legs, so you can really feel the muscle activation quite well" (P4)

The cognitive or emotional state of the patient was regarded as a bigger challenge than the physical concerns, and related to mental capacity, fatigue and discomfort of the patient.

"the child just can't cope with more things being stuck on… the child is not mentally capable enough of understanding what a maximal contraction kind of test is" (P2).

"the EMG we need to collect with a 3D system together which means, by the time we come to the 3D data it is like it's the last bit we do in our gait analysis, and very often children get more tired. And so that's a main problem" (P4).

Fine-wire EMG was reportedly used in the past by four participants and not typically within the paediatric population with patient discomfort being the main reason:

"they decided not to proceed with that [fine-wire EMG of tibialis posterior] as a diagnostic kind of tool, because of the discomfort and the, you know the, the reality of trying to get a fine wire into a small child's leg in the, in the gait lab environment" (P11).

In contrast, one participant from a lab not using EMG did not consider the patient themselves to be a barrier to using EMG: "I mean, patients generally think 'well, you're sticking another interesting measurement device thing on me, that, that's cool" (P5).

3.4.2.2. Capacity to collect good quality data. The challenge of being able to collect good quality data related to the gait lab staff themselves having lack of formal training (n = 8) and to technical issues such as noise (n = 6), data artefacts (n = 6) and technical issues with the system, although these were reported as rare (n = 4). Participants who used EMG were generally happy with the ease of integration with other systems i.e. motion capture.

"getting artefacts in your signal that you can't work out what the cause is" (P1).

"we did stop doing fine wire because the physio who was trained in that left" (P3).

"we couldn't reliably get, differentiate rectus femoris from the vastii and that was the main thing that the surgeons wanted it for" (P7).

"technical issues that will make it a bit harder to really use it" (P4).

3.4.2.3. Justifying the effort. Weighing up the value of the information gained from EMG data against training staff, obtaining normative data, and collecting and analysing patient data was a key challenge for many (n = 12).

"collecting all that data, processing all that data… So yeah, it's a lot of work" (P5).

Among all of the participants not using EMG (n = 5), justifying the effort to include EMG without clear evidence of impact to clinical decision-making was often a key barrier to implementation.

"lack of evidence to support the, that it will make a mass…, a big difference in clinical decision-making" (P5).

For seven participants using EMG, the contribution to clinical decision-making was also questioned, relating to the theme "confirmation", using EMG to support other data.

"I think it does. It does contribute. But how much of a contribution it makes is difficult to quantify" (P3).

3.4.2.4. Distinguishing true deviations from the norm. The challenge of interpreting patient data with respect to control data related to the characteristics of the normative data itself and the challenges of interpreting EMG signals. The variability of EMG within the normative database could make it difficult to identify a signal as being pathological: "in a normal database we have from trial to trial, the activation of the muscle could be different from one a step to another" (P13).

With regards to interpretation it was noted that: "you have to be careful not to over interpret things" (P8). It was noted that the challenge of interpretation can be influenced by the way the signal is processed: "thresholds are very sensitive to background noise", "because we normalise, it might simply be an effect of normalization that activity is lower here than normal" (P8).

It was also reported that interpreting true co-contraction can be complicated by cross-talk: "if you are looking at, you're trying to determine are we getting co-contraction, but in the same time you want to eliminate cross talk" (P3).

4. Discussion

The results highlight some of the challenges that may limit EMG use in clinical practice. Building upon the single-centre survey conducted by Cappellini et al. [12], this study aimed to broaden the understanding of the EMG usage and challenges across different labs in the UK and wider Europe. Two themes were identified within the data "usage" and "challenges". The "usage" theme was split into four basic themes of "activation timing", "spasticity", "confirmation" and "co-contraction" and identified how and when EMG was being used. The "challenges" theme was divided into "feasibility with a given patient", "capacity to collect good quality data", "justifying the effort" and "distinguishing true deviations from the norm" highlighting the challenges faced when using EMG or inhibiting the use of EMG.

There are various methods of quantifying EMG data identified within the literature [18], despite this, the majority of labs within this study interpreted only the raw data, primarily using qualitative interpretation of the activation timing. A qualitative interpretation of the raw data depends upon experience and knowledge of EMG, however this varied across participants within this study. The focus on activation timing rather than EMG amplitude may reflect both the nature of the clinical questions, such as the suitability of a rectus transfer tendon transfer through the identification of a prolonged rectus femoris activity in the swing phase [19], as well as the difficulty in normalising EMG in a clinical context [20]. Using only the raw data may also be due to the lack of time to process data and the computational burden within clinical practice. Our results are consistent with the initial findings of a Delphi process which focus on collecting expert opinions of using EMG to enhance diagnostic and therapeutic methods for patients with CP, within the Delphi process most descriptors used to evaluate EMG involved timing of activation such as "delayed" or "out of phase" [9]. However, our finding of gait labs interpreting only the raw data is in contrast with the findings of the ongoing Delphi consensus which found that 21 % of the experts surveyed use only the enveloped data [9]. Whether interpretation differs when using raw or enveloped data of a given case remains to be seen.

The approximate percentage of patients where EMG was used differed slightly between the UK and the non-UK labs we were able to include. The UK labs used EMG between 15 % and 50 % whereas non-UK labs used EMG on a higher percentage of patients between 25 and 90 + % (Table 3), the difference may be due to financial structures. Non-UK gait labs are typically financed through health insurance, and EMG was often part of a diagnostic package, reasons for not including EMG in non-UK labs were often related to the patient feasibility or a technical issue. In contrast, the UK gait labs are funded by the National Health Service (NHS), where teams made executive decisions whether to use EMG or not based on the referral question for each case, as well as the feasibility of patient or technical issues possibly leading to a lesser percentage of patients where EMG is used. However, we recognise that the participants from non-UK labs were only from two different countries and their views may not be generalizable to other countries in Europe. It is possible that interviewing staff from other countries could have generated other themes. For instance, we were unable to interview any gait lab staff from the Netherlands, where the "clinical technologist" has been trained in interdisciplinary competencies for 15 years [21]. The concept of data saturation, or the decision to stop the data collection as no new themes or codes 'emerge', has been contested when using the reflexive form of thematic analysis [22]. As such the decision to stop data collection was made based on when we felt we had adequate richness in the data to answer our research question and partly a pragmatic exercise, governed by the time and financial constraints of the project, as is often the case [22].

The cost of the EMG equipment did not appear to be a factor for the labs within this study but was a relevant barrier found by Cappellini et al. [12]. This could be due to the relatively cheaper cost of EMG equipment compared to the larger 3D motion capture and kinetic equipment. For those labs that do not use EMG 'justifying the effort' appeared to be the major inhibitor which related to the perceived 'lack of time'. Collecting large normative databases and creating new protocols was considered time-consuming, combined with limited evidence within the literature supporting the use of EMG in clinical decision-making. In addition, some EMG users also questioned the contribution of EMG data to the decision-making process, relating to the usage as 'confirmation'. In some cases, EMG was the piece of equipment to forgo if presented with time constraints or technical issues. However, non-EMG users within this study were open to using EMG if there were further evidence to support the use of, and benefit to using EMG in clinical decision-making. To support this the ongoing Delphi study, proposes to highlight case scenarios where EMG has been proven to be impactful in the clinical decision-making process, this may help justify the effort of using EMG in particular cases, scenarios or referral questions through decision trees, this could improve the efficiency and usage of EMG [9]. Additionally, there is a lack of literature concerning how recent advances in sensor technology can be applied to the clinical setting, particularly the potential for decomposition of surface EMG into individual motor units with high-density EMG [21].

Lack of time, difficulty of interpretation and large variations in education were reported, similar to previous findings [10,12]. Education surrounding EMG varied between participants within this study (Table 1), four participants had a deep understanding of EMG through doctoral research or intensive 3-week EMG specific courses, whereas others had only received in-house training or from others within the gait lab community. Limited education could lead to a reduced 'capacity to collect good quality data' and a reduced lack of confidence in 'distinguishing true deviation from the norm' through data interpretation. Variations in educational backgrounds was also found in previous studies [10] and suggestions have been made for open access teaching material, practical workshops [23] and knowledge translation/research papers that communicate the consensus of EMG usage including the Consensus for Experimental Design in Electromyography (CEDE) project [20,24]. Interestingly throughout the interviews there was no mention of the CEDE project, an initiative for improving knowledge translation in EMG. Merletti and colleagues [21] have discussed the need for greater translation of EMG research into clinical practice which they suggest may partly be addressed through the introduction of EMG into the physiotherapy curriculum at the BSc and MSc level and rewarding grant credits to attend EMG related workshops. The authors also suggest mandating the knowledge and application of surface EMG in clinical practice [21]. However, the present study would suggest that this strategy may be unlikely to succeed, especially in the UK, without clear evidence of the efficacy of EMG in informing clinical decision making. Training for existing staff may be best focused on the technical aspects such as interpreting the signal, identifying artefacts and best practices for processing the data as well as the clinical interpretation.

This study interviewed professionals working within gait analysis labs, the majority of participants were either physiotherapists (n = 6) or clinical scientists (n = 6) directly involved in collecting and interpreting EMG data. However, we only interviewed one orthopaedic surgeon, interviewing more surgeons who often refer patients for a clinical gait analysis and are responsible for treatment decisions could provide further insight into the impact EMG has on clinical decision-making. Additionally, interviewing more labs that do not currently use EMG would further the understanding of the reported decline in the use of EMG [4]. Although the heterogeneity of our sample limits our ability to draw definitive conclusions, we considered it informative to include the breadth of roles working with EMG. Equally the views regarding the challenges and usage of using EMG by one individual do not necessarily reflect the views of other professions within the same team.

5. Conclusion

Interpreting EMG signals can be challenging and time-consuming. For EMG to be more widely and routinely used in clinical gait labs, the perceived effort of staff and patients would need to be justified by a clear link to the treatment planning and decision-making through further published evidence and educational training.

CRediT authorship contribution statement

H. Shepherd: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Investigation, Funding acquisition, Data curation. **J. Reeves:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **C. Stewart:** Writing – review & editing, Supervision, Conceptualization.

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Declaration of Competing Interest

All named authors have no conflicts of interest to disclose.

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