STABILITY OF GLOBAL SYNKINESES IN CHRONIC STROKE SUBJECTS

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ABSTRACT

Background and purpose: Global synkineses [GS] are non-purposive associated movements on the affected side of hemiparetic subjects [HS] triggered during a voluntary effort. GS appear in a predictable fashion with well-established torque patterns. The purpose of this study is to assess the stability and consistency of GS measurements during multiple trials (n=3) and sessions (n=3) in chronic HS.

Method: A convenience sample of fourteen chronic (i.e. time post CVA >1 year) HS was evaluated. GS on the affected upper limb of the HS were quantified with static multiarticular dynamometry and surface electromyography during maximal contralateral hand grips. Reliability and stability of GS torques and electromyographic measurements were assessed using the index of dependability and standard error measurement (SEM) in a decision study (D-study).

Results: Increases in the contralateral maximal hand grip force between the first and subsequent sessions were accompanied both by increases in the amplitude of elbow flexion torques and by elbow flexor muscle EMG activities. Indices of dependability for torque (.53 to 75) and EMG (.34 to .70) GS measurements for one session and one trial were low. However, reliable quantification of GS and acceptable SEMs were achieved with the use of two separate measurement sessions and two trials per session.

Conclusion and Discussion: GS in chronic HS are relatively stable and most pronounced at the elbow. However, they are force sensitive and demonstrate change between measurement sessions. This change seems to depend on the level of voluntary force exerted and possibly, on the spasticity of the subject.
Further research should focus on the standardization of a GS measurement protocol.
INTRODUCTION

Involuntary movements occurring during voluntary efforts are generally referred to as associated movements. Global synkineses (GS) are pathological, non-purposive, associated movements on the involved side of hemiparetic subjects (HS) triggered during a voluntary effort. Their occurrence is common and is elicited in the hemiparetic limbs during voluntary forceful resisted contractions on the contralateral side. They may be altered with changes in head position and spasticity. The onset of the GS is delayed in relation to the voluntary effort and it generally involves different muscle groups than those utilized during the force generation.

Despite the fact that GS have been described extensively in the clinical literature and are well recognized by clinicians, few studies have looked at GS from a quantitative perspective. The majority of assessments have used observational approaches based on frequency measurement or case studies. In recent years, a novel experimental approach has been developed to quantify GS during contralateral maximal grip exertions on the non-affected side of HS. This approach is based on multiarticular static dynamometry and electromyography. The results show that while no significant contralateral torques or EMG are observed in control subjects, GS are graded with the severity of the hemiparesis and the spasticity in the hemiparetic subjects. The most prevalent and strongest GS torques recorded were in elbow flexion. The highest levels of hand grip force elicited the greatest GS in HS.
While the patient’s ability to control GS is generally considered an index of their motor performance, controversy still remains regarding treatment approaches. There is no consensus on whether to attempt to reduce the synkinetic movement, or to capitalize on the movement in the early stages of recovery in hemiparesis. Furthermore, developing control over GS in HS has not been examined experimentally. There is a lack of convincing quantitative evidence that such change in behavior improves motor performance.

Investigations of these matters cannot be seriously considered or rigorously executed without first defining the characteristics and functions of GS in HS and their changes with time or therapy. This can be done through standardized quantitative assessments. The purpose of the present study is to assess the stability and consistency of GS during multiple trials and experimental sessions in chronic stroke patients. Partial results of this study have been presented in abstract form.
METHODS

Subjects

This study was approved by the hospital’s ethics committee and the subjects gave their informed written consent prior to the experimental procedures. Fourteen chronic hemiparetic subjects consisting of 10 men and 4 women between the ages of 28 years and 63 years (mean ± SD: 46 years ± 12 years) participated in this study. The HS were recruited from a university secondary care rehabilitation center and were included in the study if they: i) had sustained a single cerebro-vascular accident (CVA) leading to upper limb paresis at least one year prior to the experiment, ii) lived within 30 km of the research center, iii) were able to understand simple commands (no receptive aphasia) and, (iv) showed no severe cognitive or comprehension deficits. Patients with trocular lesions as documented in their medical history were not considered. Before the experimental testing, the global motor performance was evaluated with the Fugl-Meyer scale 21 and the Chedooke-McMaster Deficit Assessment Scale 23, 24. Muscle tone in elbow flexors and extensors was evaluated using the modified Ashworth scale 25, 26. Detailed clinical data for HS is shown in Table 1.

The cause of lesion was diagnosed as either ischemic (n=9) or hemorrhagic (n=5). Eleven subjects presented right side hemiparesis and 3 subjects presented left side hemiparesis. The mean time post-CVA was 4 years and ranged from 1.3 to 7.2 years. The scores on the Fugl-Meyer motor performance test ranged from 11 / 66 to 63 / 66 on the upper limb scale with group mean of 30 / 66. Upper limb scores on the Chedooke-McMaster deficits scale ranged from stage 2 to stage 6. Spasticity scores on the modified Ashworth scale ranged from
0 to 2 for spasticity in elbow flexors and form 0 to 3 for spasticity in elbow extensors.

Protocol and experimental design

Global synkineses are operationally defined as the torques and EMG activities recorded on the affected upper limb at 100 % of a progressive maximal voluntary grip exertion (MVG) on the non-affected side. Three measurement sessions held at approximately the same time of day were separated by 1-week interval. During each session, a maximal voluntary grip force (MVGF) target value was used as a reference value to scale the ramp templates. It was determined to be the highest value recorded during three consecutive maximal voluntary grip attempts. Subjects were instructed to follow as closely as possible the ten-second force ramp template presented on a computer screen. The subjects had to reach their MVGF target and maintain or surpass it during the last second. Three consecutive grips with a one-minute rest interval were executed with verbal encouragement.
Instrumentation

Grip forces were recorded using a modified prehension dynamometer\(^*\) instrumented with a universal tension adaptor coupled to a transducing cell\(^\dagger\) interfaced with a computer\(^\ddagger\). Torques exerted simultaneously in shoulder flexion-extension \([S1]\), abduction-adduction \([S2]\), internal-external rotation \([S3]\), elbow flexion-extension \([E1]\) and forearm pronation-supination \([E2]\) during the contralateral grips were recorded using a static multiarticular dynamometer. Subjects were seated in a wheelchair\(^a\) with their trunks secured using straps. The wheelchair was positioned on a uniform X-Y grid marked on the floor. Movement was prohibited by a breaking mechanism limiting forward and backward sways as well as the rotation of the chair. A back support system was used to immobilize the back throughout the protocol. The affected upper limb was placed into two fixation rings rigidly mounted through force transducers to a metallic structure bolted to the floor and to the adjacent wall (Figure 1).

\[\text{INSERT FIGURE 1 AROUND HERE}\]

The position of the upper limb in the apparatus was fixed with the elbow flexed at 90°, the shoulder in 30° of abduction and 10° of flexion, and the forearm in neutral position. The strain gauge based force transducers were interfaced with a computer that recorded forces exerted at the arm and distally at the wrist. Following the subject’s limb positioning in the fixation rings, external lever arms were measured with an anthropometrical caliper\(^\S\). A computer program then calculated in real time according to static equilibrium equations the muscular torques exerted in each specific anatomical plane of movement of the shoulder, elbow, and forearm. Further details on the functioning of this dynamometer are available elsewhere \(^18, 19\).
EMG activity of the biceps brachii (BB), brachioradialis (BR), triceps brachii (TB) and flexor digitorum [FD] of the affected upper extremity (limb fixated in the apparatus), was recorded during the contralateral grip tasks. The surface electrodes were placed along the axis of the muscle fibers. The detection surfaces of these high input impedance electrodes consisted of two parallel silver bars, each 1.0 cm long and 1 mm wide, spaced 1.0 cm apart. The electrodes were placed on the upper part of the short head of the muscle for the BB, two cm from the biceps crease on the belly of the BR, on the most prominent part of the belly of the lateral portion of the muscle for the TB and on the proximal portion of the FD. Signals were pre-amplified (CMRR = 120 dB, gain = 2000 and band passed at 10Hz to 500Hz) and digitized on line at a frequency of 2000 Hz using an acquisition card.

Data processing

Torque (5 torques) and EMG (4 muscle EMGs) values recorded at 100 % of the maximal voluntary grip force [MVGF] during each trial of each session were used to measure synkinesis. The highest grip force value was used as the 100 % MVGF reference point. Root mean square (RMS) EMG values of the BB, BR, TB and FD muscles and mean torques (Nm) in S1, S2, S3, E1, E2 were then averaged over a 256 ms window around this reference value. Data processing was executed with the Labview software program.

Typical global synkineses
Typical global synkineses on the affected upper limb of one hemiparetic subject recorded during a maximal grip ramp exertion on the non-affected side is shown in Figure 2. Torques and EMG activities on the affected side increase rapidly after about 7 seconds or 70% of the MVGF and peak between the eleventh and twelfth second when the MVGF grip is reached. This suggests that global synkineses are elicited only at a certain relative force threshold and that peak absolute force influences the magnitude of global synkineses. In this study torques and EMG values were extracted at the highest grip force generated during the tasks to account for the aforementioned peak.

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Statistics

Stability and consistency of dynamometric and electromyographic measurements of GS were established based on the generalizability theory. A generalizability study (G-study) and a decision study (D-study) were computed for all measurements and the consistency of each measurement was estimated using the standard error of measurement (SEM) 27, 28. All of the statistical analyses were performed on the GENOVA* program developed specifically for the generalizability analysis 29.
RESULTS

The mean grip force, contralateral torque and EMG activities recorded during the 3 measurement sessions appear in Figure 3. Group means were computed from average (n=3 trials) torques and EMG values. With the exception of E2, all torques and EMG values were significantly different from zero (p<0.001). Mean torques reached 4 Nm in shoulder flexion (S1), 10 Nm in shoulder adduction (S2), 2 Nm in shoulder internal rotation and 16 Nm in elbow flexion. Significant mean EMG activity (i.e. between 50 and 100 Uv) was recorded in the biceps brachii (BB), the brachioradialis (BR) and the flexor digitorum (FD). Mean maximal contralateral hand grip forces increased between the first experimental session and the subsequent experimental sessions. This increase represents a force increase of approximately 9 %. The mean maximal hand grip force remained stable between the second and third experimental session. Mean torques and EMG activities recorded in shoulder flexion (S1), shoulder adduction (S2), elbow flexion (E1), biceps brachii (BB) and brachioradialis (BR) also increased between session 1 and subsequent sessions. These increases were more pronounced for the torques than for the EMG.

_________INSERT FIGURE 3 AROUND HERE_________
G-study on global synkineses measurements

Unbiased estimates of each source of variance for GS torque and EMG measurements and the percentages of the attributable variance appear in Table 2. Results for GS torque measurements show that the largest proportions of the total variance were attributable to the subjects’ scores (53 % - 76 %) followed by the interaction between subjects and session (12 % - 33 %) and the triple interaction among subject-session-trial (6 % - 12 %). The proportions of the total variance attributable to the trial and session effects were negligible, with the exception of the torque in E1 where a session effect was noted (8 %).

Similar results were observed for GS EMG measurements in BB and TB muscles. For these muscles the most important sources of variance were also the subjects’ scores (52 % - 70 %), followed by the interaction between subjects and session (19 % - 27 %) and the triple interaction among subject-session-trial (5 % - 19 %). However, for the BR and the FD muscles, the proportions of the total variance attributable to the subjects’ scores were lower (24 % - 34 %) and those attributable to the subject-session interaction (30 % - 40 %) and subject-session-trial interaction were higher (29 % - 27 %). Although the percentages of the total variance attributable to the trial and session effects for BB, TB and FD muscles were negligible, a session effect was noted for the BR muscle (9 %)

__________INSERT TABLE 2 AROUND HERE__________
D-study on global synkineses measurements

The results of the D-study for all combinations of factors (session and trial) appear in Table 3. Indices of dependability and standard error measurements for GS torque and EMG measurements are presented. It should be noted that the index of dependability for one occasion and one repetition calculated in the D-study corresponds to the intraclass correlation coefficient that would be calculated from a two-way analysis of variance (ANOVA). The SEM represents the consistency between the trials and sessions, in clinically relevant units of measurement.

INSERT TABLE 3 AROUND HERE

Torque measures

Indices of dependability for one session and one trial for torque measurements of GS are generally low. They increase in value from .53 for E1 and S1 torques, .58 for the torque in S2, .67 for the torque in S3 and .75 for the torque recorded in E2. The SEMs for one session and one trial were between 4 Nm and 6 Nm excluding the E2 torque (.63). Increasing the number of trials in one session had little influence on the indices of dependability and the SEMs. However, the combination of trials and sessions improved the stability of the GS torque measurements. The addition of one trial and one session increased the indices by an average of 20 % and improved the reliability of the GS torque measurements to an acceptable level (.72 to .88). SEMs were lowered on average by 39 % under these conditions and were 3.30 Nm for S1, 3.82 Nm for S2, 2.32 Nm for S3, 3.86 Nm for E1 and 0.41 Nm for E2. The addition of two trials and two sessions resulted in the highest indices observed but contributed to an average increase in the indices of 22 % from the original condition, or an
increase of 2% in comparison to the previous condition. The differences in SEMs between the two conditions were generally small (i.e. less than 0.5 Nm).

EMG measures

While indices of dependability for one session and one trial were extremely poor (.24 -.34) for EMG recorded in BR and FD, values for BB and TB were similar to those reported for torque measurements (.52 - .70). The SEMs were, with the exception of the EMG in TB (11 Uv), on average 36 Uv for one session and one trial. As observed for torque measurements, increasing the number of trials in one session had little influence on the indices of dependability and the SEMs. However for BB and TB, the addition of one trial and one session increased the indices by an average of 20 %, reaching similar levels as those observed for torque measurements. The SEMs for these two muscles under those conditions were respectively 21 Uv for BB and 7 Uv for TB. Additional sessions and trials did not increase the reliability and consistency of GS EMG measures for either the BB or the TB muscles.
DISCUSSION

GS in HS have been shown to appear in a predictable fashion with well-established torque patterns 3-5, 10, 11. The objective of this study was to assess the stability of GS in chronic stroke subjects with different levels of hemiparesis using a quantitative experimental approach based on static dynamometry and electromyography. There is an inherent natural variability of torque and EMG measurements with repeated measures in both the normal and the pathological populations. With this consideration, inter-session and inter-trial comparisons of GS patterns and amplitudes during contralateral hand grip exertions indicate that GS are fairly stable in chronic hemiparetic subjects.

In this study, significant torque and EMG activities, particularly at the elbow, were seen at high levels of voluntary exertion. Patterns and amplitudes of torque and EMG activities were similar to those previously reported for another group of HS 30 with the exception of the torque recorded in shoulder abduction-adduction. The predominant manifestation of GS is the activity (i.e. torques and EMGs) recorded in elbow flexors. This also corroborates previous observations 30 and indicates that elbow flexors play an important role in GS.

However, the position of the affected upper limb seems to have had an influence on the pattern of GS recorded during contralateral hand grip exertions. In the previous study, using the same experimental set-up and a similar protocol, the pattern of torques recorded in shoulder abduction-adduction was reversed (i.e. shoulder abduction dominating). The only apparent change from one
experiment to the other was the position of the arm in the dynamometer. In the first experiment, the arm was positioned with an abduction angle of 15° or less and 0° of shoulder flexion. In this experiment the arm was positioned between 30° and 45° of shoulder abduction and approximately 10° of shoulder flexion.

Changes in the position of the arm segment within the apparatus between studies could account for the reversal of torque patterns observed in shoulder abduction-adduction GS. Replication of previous results adds further validation to the current experimental approach and additionally offers support for its development and standardization as a tool to study GS. However, important variations in GS were observed and the sources of these variations need to be addressed.

Reliability of GS

A phenomenon is considered to be reproducible and stable when the variation attributable to the subjects is large compared to other sources of variation. In this study, the subjects’ variance, for most of the GS measurements, represented between 50 % to 60 % of the total variance. Variances due to the session effect for most GS measurements were negligible. However, a session effect was observed for the torque recorded in elbow flexion and the EMG recorded in the brachioradialis. No trial effects were observed. The subject-session interaction and the variances attributable to the triple interaction (subject-session-trial), were the second and third most important sources of variance. Variances associated with the subject-trial and session-trial interactions were generally low.
GS recorded on the first measurement sessions were lower than those observed in the second and third measurement sessions for some subjects. This is shown by the combination of the variances attributable to the session effect (elbow flexion torques and the brachioradialis EMG) and the subject-session interaction. Several possible factors could explain these changes. The mean absolute level of hand grip force generated in the first session was lower than those recorded in subsequent sessions. Interestingly, the amplitudes in torque and EMG recorded at the elbow were also lower in the first session than the other sessions. The absolute level of the voluntary exertion, in terms of the force generated by a given subject, could have influenced the amplitude of GS recorded in HS. Mirror movement in healthy subjects and muscular overflow of voluntary effort in healthy subjects and pathological subjects have been shown to increase with the level of voluntary exertion during various tasks. 34-41. This suggests that in addition to appearing at high levels of voluntary exertion, GS in HS may also be force dependent.
Spasticity could have contributed to the variance attributable to the triple interaction subject-session-trial. This interaction represents the residual error related to the unmeasured factors that had effects on the stability of the values. Spasticity or a certain degree of hypertonicity is considered a pre-requisite condition governing the development of GS in hemiplegia. Previous observations show that the level of spasticity and the severity of motor deficits in HS is associated with the severity of GS. Although the testing was conducted, as much as possible, at the same time of day for each session, fluctuations in spasticity due to external and environmental factors could have influenced the level of GS recorded in certain hemiparetic subjects. Positional changes of the head and their influence on tonic neck reflexes have also been shown to increase GS in HS. In this study, the head of each subject was not stabilized in any way during the tasks. However, the position of the monitor used to give the visual feedback on the ramp exertion precludes any significant positional changes of the head in the range necessary to evoke tonic neck reflexes.

Variances attributable to the trials as well as to the subject-trial interaction were small. No systematic changes from one trial to the next were observed. This suggests that GS are stable across repeated trials within a single measurement session. In addition, under controlled conditions (i.e. 60 seconds rest period), repeated voluntary grip exertions (n=3) have no significant facilitatory or inhibitory effect on the amplitude of GS. This contradicts previous observations on muscular overflow in normal subjects which showed that involuntary EMG activity recorded from contralateral segments during resisted
movements increased with repeated trials\textsuperscript{38, 45, 46}. It remains to be seen whether the cumulation of a larger number of trials affects the amplitude of GS and if central and/or peripheral fatigue influences GS.

Clinical impact

The results of the D-study characterized the impact of the number of repetitions and occasions on the stability of the GS measurements. Indices of dependability for a given number of trials increased significantly and SEMs were lowered when additional measurement sessions were included. Additional trials in any given measurement session did not contribute to significant changes in these values. These results corroborate previous observations made by Stradford et al. (1989)\textsuperscript{27} on grip strength measurements. They suggest that in order to obtain reliable quantification of GS and acceptable SEMs using dynamometric and electromyographic measurements, the best approach is to use at least two separate measurement sessions and two trials per session. Furthermore, the use of a preliminary familiarization session to reduce the learning effect seen in the first session could also enhance the reliability and consistency of GS measurements.
The standard error measurement (SEM) expresses measurement error in the same units as the original measurement. These values have clinical relevance for therapists who may establish when there is a true difference in GS rather than an error of measurement. As variance is often proportional to the mean, it is advisable to compare SEMs with the corresponding mean values of the measures. In our study the importance of the SEMs of electromyographic and dynamometric measurements of GS in relation to their mean value varied greatly from one measure to another. Since the torque in elbow flexion is the predominant manifestation of GS observed in HS, we will consider it the most relevant for this analysis. For example, the SEM of GS recorded in elbow flexion torque for one experimental session and one repetition represents 37% of the mean GS recorded in elbow flexion (SEM=5.9 Nm / 15.91 Nm x 100). This would indicate that in order to assess the efficiency of any therapeutic intervention aimed at inhibiting or promoting GS, changes representing more than 37% of the initial value recorded in elbow flexion are necessary to reflect changes other than the measurement error of GS. Awareness of these limitations can guide the planification and execution of the therapeutic intervention. However, overestimation of the error may occur with a small sample and SEM results should be interpreted with caution. Larger samples are needed to stabilize the estimates and obtain more accurate SEMs for electromyographic and dynamometric measurements of GS. This is particularly important for GS recorded in joints other than the elbow.
Research avenues

In order to understand the contribution of GS to movement disorders in HS and to evaluate the relevance of using or inhibiting them in rehabilitation practices, further quantitative studies are needed. Research avenues for the study of GS in HS are threefold: 1) to develop and standardize a measurement protocol for the quantification of GS; 2) to adapt and transfer this measurement protocol to clinical settings to study GS in the acute phase of stroke; 3) to combine this measurement protocol with electrophysiological testing to attempt to pinpoint the neurophysiological mechanisms involved in GS and ultimately, 4) to evaluate the effects of different therapeutic interventions using or restraining GS in HS and the outcome on functional recuperation.

With the increasing use and availability in clinical settings of hand-held dynamometers, grip dynamometers and EMG biofeedback equipment, it appears plausible that the methods and protocol for the quantification of GS presented in this paper could be adapted and transferred to the clinic. Use of hand-held dynamometers is increasing and they have been found to be reliable for the measurement of static muscle contraction and for passive movements (reflex activation). Existing protocols on the use of hand-held dynamometers could be adapted for the assessment of GS. The impact of studying GS and their manifestations in acute stroke subjects through the incorporation of the assessment of GS with existing evaluations, could greatly contribute to further our understanding of the nature of GS. This information could generate possible theories on the neurophysiological mechanisms involved in GS. For example,
although spasticity or hypertonicity is generally considered to be a pre-requisite condition governing the development of global synkineses in hemiplegia, no study has yet combined electrophysiological or biomechanical testing of spasticity and quantitative measures of GS to explore the relationship. Furthermore, there is no prospective quantitative data in the literature on spasticity changes in acute stroke subjects and their effect on GS. Documentation of these matters could well dictate how we deal with GS in HS.
CONCLUSION

Global synkineses in chronic HS were quantified with static dynamometry and electromyography during repeated contralateral hand grip exertions and compared in three experimental session, one-week apart. Results show that GS, measured with static dynamometry and electromyography, are relatively stable phenomena in chronic stroke subjects during repeated measurement sessions. It was also shown that repeated measurements with controlled rest periods within a single measurement session do not influence the magnitude of GS observed. The dynamometric and electromyographic measures also indicate that involuntary torque and EMG activities in elbow flexors are the predominant manifestations of GS in HS. These manifestations are force sensitive and vary depending on the absolute level of force exerted during a task. While some of the details on the experimental context in which GS appear in HS have been defined, many questions remain unanswered. It is hoped that the results and experimental approach used in this study can serve as a building block toward the establishment of a standardized measurement protocol. This protocol could be applied in clinical settings to study GS in acute stroke and eventually further the understanding of the role and nature of GS in stroke.
REFERENCES


FIGURE CAPTIONS

FIGURE 1. General overview of static bi-articular dynamometer used to measure torques exerted simultaneously at the shoulder, elbow, forearm.

FIGURE 2. Typical pattern and magnitude of contralateral shoulder, elbow and forearm torques (Nm) and EMG recorded on the affected upper limb of an hemiparetic subject during a maximal 10-second ramp grip exertion on the non-affected side. The hand grip force generated during the ramp task appears in the left upper portion of the graph (HG). Note that the torques in shoulder flexion (S1), shoulder adduction (S2), shoulder internal rotation (S3), elbow flexion (E1), forearm pronation (E2), and EMG activity in biceps brachii (BB), brachioradialis (BR), triceps brachii (TB) and flexor digitorum muscles on the affected upper limb start only at high levels of contralateral hand grip force (HG) and then increase rapidly with increasing grip force, with peaks around the maximal grip force generated by the subject. For this study, mean torques and EMG values were extracted from 256 ms windows at the highest grip force value recorded by each subject.

FIGURE 3 Reliability of global synkineses (GS). Results represent the mean hand grip force and GS (i.e. torques and EMG) computed from 3 trials in each measurement session. Mean and standard error (Ste) maximal voluntary hand grip force (MVGF), upper limb torques and root mean square (RMS) EMGs recorded at 100% of the MVGF during contralateral maximal 10-second ramp grip exertions performed on the non-affected side of 14 hemiparetic subjects (HS) are illustrated. Note the increases in grip force in the second and third sessions from the first session.
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