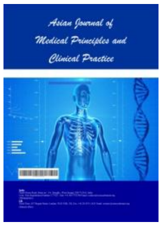

Asian Journal of Medical Principles and Clinical Practice

4(4): 29-42, 2021; Article no.AJMPCP.71792

Latency to Peak Electromyographic Activation in Lower Limb Movement Patterns Described by Kabat: Timing of Selected Muscles

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MVB, JCR and JEPP participated in all phases of the project: design, data collection, analysis of results, and preparation of the manuscript. All authors read and approved the final manuscript.

Article Information

Editor(s):
(1) Dr. Kumud Kumar Kafle, Tribhuvan University, Nepal.
(2) Prof. Suprakash Chaudhury, Dr. D.Y. Patil Medical College, India.
Reviewers:
(1) Ana Cláudia Tavares Rodrigues, São Paulo State University, Brasil.
(2) Fatemeh Rahimi, Jundishapur University of Medical Sciences, Iran.
Complete Peer review History: https://www.sdiarticle4.com/review-history/71792

Original Research Article

Received 05 June 2021
Accepted 10 August 2021
Published 14 August 2021

ABSTRACT

Objective: To determine the activation sequence of selected muscles, in supine and standing positions, by means of the latency to peak electromyographic (EMG) activation in the movement patterns of the lower extremities described by Kabat.

Methods: A comparative analytical study was conducted with an intentional sample of healthy adults between 18 and 25 years old, 20 men and 20 women with right foot dominance. Three active repetitions of the two lower limb diagonals were performed, in both supine and standing positions. The latency to peak EMG activation for eight muscles in the four movement patterns was recorded by surface electromyography. The sequence of contractions was determined by means with their 95% confidence intervals. Tests of homogeneity between positions were carried out.

Results: In most patterns, a sequence of proximal to distal contractions was observed. Significant differences between supine and standing positions were only evident in nine of the 64 trajectories studied ($p<0,05$).

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Conclusions: These results partially contradict the theory of normal timing that postulates that the sequence of muscle contractions is performed from distal to proximal. Future studies should include a greater number of muscles and assess other variables such as the first contraction evidenced in the electromyographic tracing.

Impact Statement: The variability found in the sequence of maximum muscle activation during the execution of lower limbs movement patterns described by Kabat, suggests that the concept of normal timing is linked to the execution of a facilitation technique through a pattern, and not to the pattern itself. This depends on the objective of the task and the individual characteristics of the subject. The need to individualize the normal timing and adapt the timing for emphasis according to each person is evident.

Keywords: latency period; muscle contraction; proprioceptive neuromuscular facilitation; lower limbs; electromyography.

1. INTRODUCTION

The timing is a widely used concept within the framework of the Proprioceptive Neuromuscular Facilitation method or Kabat method defined as the sequence of dynamic muscle contractions during any activity in which a coordinated movement occurs [1]. Normal timing is then constituted as a fundamental property to achieve an adequate functional result, because it involves the controlled interaction between mobility and stability [2], that is managed by an adequate neuromuscular control responsible for the development of appropriate recruitment patterns to regulate the time and force of contraction, to cause an efficient movement and to provide dynamic joint stabilization [3].

It is also considered as part of the movement patterns, defined as the combination of movements in two or more body segments and arranged according to a specific spatio-temporal arrangement [4]. As described by Kabat, they are patterns consisting of the combination of movements in all possible planes of each joint and the proximal joint acts as a pivot-axis causing a diagonal and spiral movement by describing two diagonals, and each consists of two patterns that are antagonistic to each other [5,6].

Therefore, the correct and coordinated execution of these patterns depends on an effective sequence of muscle contractions occurring in a specific order with an overlapping as the muscle is taken from its range of full elongation to its range of shortening [7].

In therapeutics, timing has been used frequently as part of procedures / techniques in order to provide continuous and coordinated movement during a task and to direct the effort of a strong contraction towards weaker muscles by following the principle of irradiation [8]. For these purposes, timing has been used respectively as normal timing and timing for emphasis, the latter being a procedure that entails the restriction of movement in a strong synergist within a movement pattern, which needs deep knowledge of its normal sequence [9].

Despite considering normal timing as an intrinsic factor of movement patterns, and its restoration a clear objective in any field of action of the physiotherapist, there is a lack of recent studies to validate a timing of selective movement patterns (referred to as the combinations of movements in two or more segments of the extremities) [4], unless it is within the framework of the task, the functional activity or the practice of a sporting gesture [10].

This differs with respect to the basic movement patterns, which develop from the combination of movements with the involvement of the axial skeleton and that themselves represent transfers, transitions and / or displacements4. This explains the interest of normal timing in them analyzes.

To this regard, the patterns of movements described by Kabat are selective patterns that have been rarely studied from their simple execution, without a clear intentionality and the mediation of a facilitation technique. This situation is worse when considering lower limb movement patterns accounting for scarce available evidence, with an exception of the flexor pattern of the first diagonal, that resembles the kick gesture and is studied as a sport gesture.

Knowing the normal timing of muscular contractions of the movement patterns described by Kabat, postulated until now in an intuitive way, will allow the application of therapeutic procedures of "proprioceptive neuromuscular facilitation" with scientific basis. It will allow the use of manual resistance by the rehabilitator, according to this sequence of contractions, achieving an adequate timing for the emphasis, which is a therapeutic principle for the muscular reeducation of the Kabat method.

Under the above, the objective of this study was to determine the sequence of muscle contractions, in supine and standing positions by measuring the latency to peak EMG activation in the lower limb patterns described by Kabat.

2. MATERIALS AND METHODS

2.1 Study Design

This comparative analytical study (homogeneity analysis) was conducted under a quantitative design. The latency to peak EMG activation of the lower limbs in supine and standing positions of healthy people was measured with electromyography of surface (sEMG).

2.2 Sample Size

An intentional sample of healthy young adults between 18 and 25 years was selected. The sample unit was composed of students from a Colombian university who met the inclusion and exclusion criteria and signed the informed consent form as acceptance. Those with severe retractions of the iliopsoas and hamstring, and with health conditions or injuries hindering the execution of movement patterns were excluded. The sample size was determined through a pilot test of twenty participants in a supine position of their gluteus maximus muscle and by the use of a formula for comparison of means. The estimate consisted of a confidence level of 95%, a statistical power of 85% and an expected difference between latencies in supine and standing positions of 14% as well as a standard deviation of 21% during the movement pattern, resulting from the average of the deviations in the four movement patterns for the minimum sample of 40 participants.

2.3 Participants

20 men and 20 women with an average age of 20 years were evaluated. All were right foot dominant and most of them had a normal weight. There were no severe muscle retractions, except in the hip adductors (65% of cases), with no alteration in the correct execution of the movement patterns (Table 1). Fig. 1 illustrates the participant flow diagram.

2.4 Procedure

Each participant performed three active repetitions without external resistance of the two diagonals of lower limbs described by Kabat[1] and the knee always in extension [1]. The flexor and extensor patterns were performed sequentially, each one of them with a dynamic phase at normal pace and a three second isometric phase at the end of the movement pattern (Fig. 1). Half of the participants started in standing position and the other half in supine position.

The preparation of the skin and the placement of the electrodes were carried out according to the European guidelines for sEMG - SENIAM (Surface EMG for a non-invasive assessment of muscles) [11-13]. The protocol defined for the EMG team of the Movement Analysis Laboratory of the Universidad Autónoma de Manizales was followed: eight-channel dynamic electromyograph *BTS FREEEMG1000*, 4G technology for sEMG analysis, entirely based on wireless technology, with a 1 KHz acquisition frequency. Eight miniaturized probes with lightweight active electrodes were used for signal acquisition and transmission. These probes contain two poles, a larger active pole or mother (rectangular 41,5x24,8x14 mm) where there are also circuits in charge of signal amplification (10 Hz active high-pass filter and 750 Hz alising) and transmission of data (up to 20 meters in free space). The second or satellite pole, with a smaller dimension (Ø 16x12 mm), acts as the ground pole or reference. Both poles capture and amplify the EMG signals, digitize them and communicate with the USB receiver connected directly to the computer or Workstation to be visualized in real time.

For the EMG analysis, the best diagonal of each participant was taken, that is, the one that, in the

[1] D1 Flexor: hip in flexion, adduction and lateral rotation; knee in extension; ankle in dorsiflexion and inversion.
D1 Extensor: hip in extension, abduction and medial rotation; knee in extension; ankle in plantar flexion and eversion.
D2 Flexor: hip in flexion, abduction and medial rotation; knee in extension; ankle in dorsiflexion and eversion.
D2 Extensor: hip in extension, adduction and lateral rotation; knee in extension; ankle in plantar flexion and inversion.

opinion of the researchers, through video analysis, will show the best excursion of all the components of the movement patterns.

The EMG signal processing was carried out in the *BTS SMART Analizer* software, following the following specifications:

a) Rectification of the EMG signal of the eight muscles: "rectify an object track relative to the middle object track"
b) Filtering the rectified signal with a butterworh low-pass filter with a cut-off frequency of 2 Hz
c) Obtaining the RMS of the signal using a moving window with a time width of 200 milliseconds
d) Capture the frequency spectrum using the Fourier transform
e) Normalization of the signal with respect to two events
f) Calculation of the peak EMG activation according to the segmentation of the EMG signal obtained from the event marking.

Using the *BTS SMART Clinic* software, the EMG signal was segmented by marking the following relevant events for the analysis of movement: dynamic start of the flexor pattern, start and end of the isometric phase of the flexor pattern (start of the phased dynamics of the extensor pattern), beginning of the isometric phase of the extensor pattern and end of the extensor pattern (Fig. 2). Marking of peak EMG activation, for each of the eight muscles in the four movement patterns, was performed automatically by the system. Each of them was empirically validated by the researchers.

2.5 Measurements

The latency to peak EMG activation was measured for each one of the eight evaluated muscles (rectus abdominis, ipsilateral spinal erector, contralateral spinal erector, gluteus maximus, rectus femoris, biceps femoris, tibialis anterior and soleus) in the four movement patterns, in both supine and standing positions. These latencies were estimated in percentage units according to the location of the peak EMG activation within the movement pattern. The latency of each muscle was measured in each pattern of both diagonals in both positions for a total of 64 records per participant.

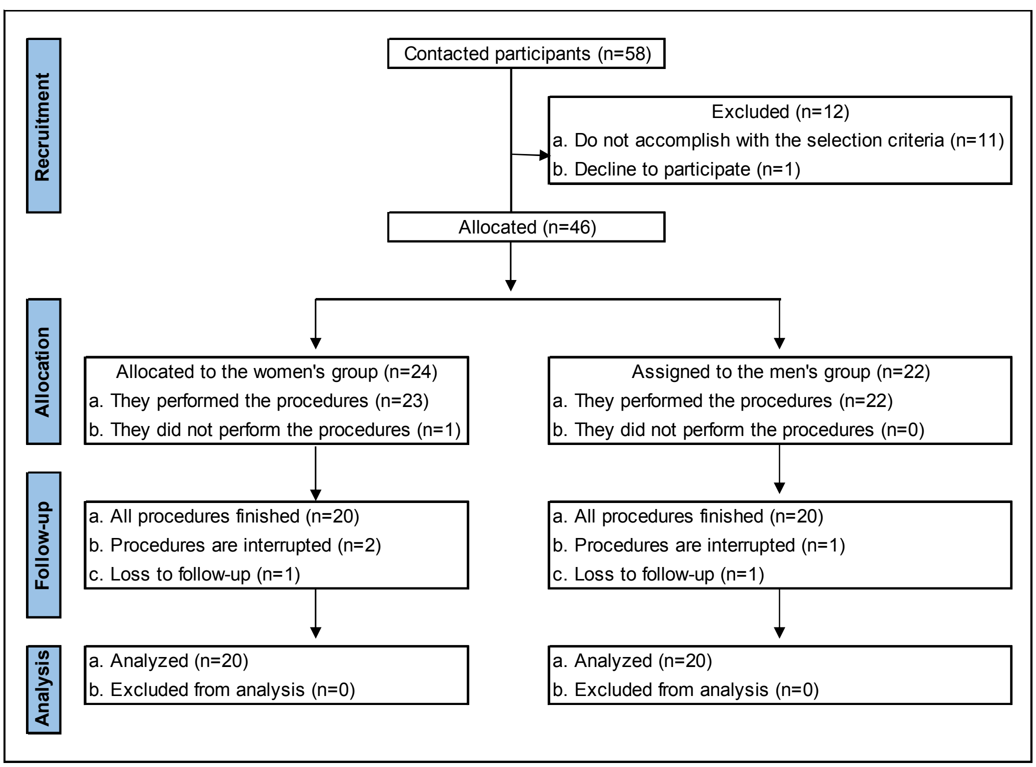

Fig. 1. Sample and participant's flowchart

Table 1. Descriptive of qualitative sociodemographic and functional variables

Test	Rating	Frequency	
Gender	Female	20	50,0%
	Male	20	50,0%
Weight status	Underweight	3	7,5%
	Normal Weight	30	75,0%
	Obesity	6	15,0%
	Overweight	1	2,5%
Right hip flexors flexibility	Normal	2	5,0%
	Slight retraction	36	90,0%
	Moderate retraction	1	2,5%
Left hip flexors flexibility	Normal	5	12,5%
	Slight retraction	33	82,5%
	Moderate retraction	2	5,0%
Rear train flexibility	Normal	29	72,5%
	Retraction	11	27,5%
Right hip adductors flexibility	Normal	1	2,5%
	Slight retraction	7	17,5%
	Moderate retraction	8	20,0%
	Severe retraction	24	60,0%
Left hip adductors Flexibility	Normal	2	5,0%
	Slight retraction	5	12,5%
	Moderate retraction	7	17,5%
	Severe retraction	26	65,0%

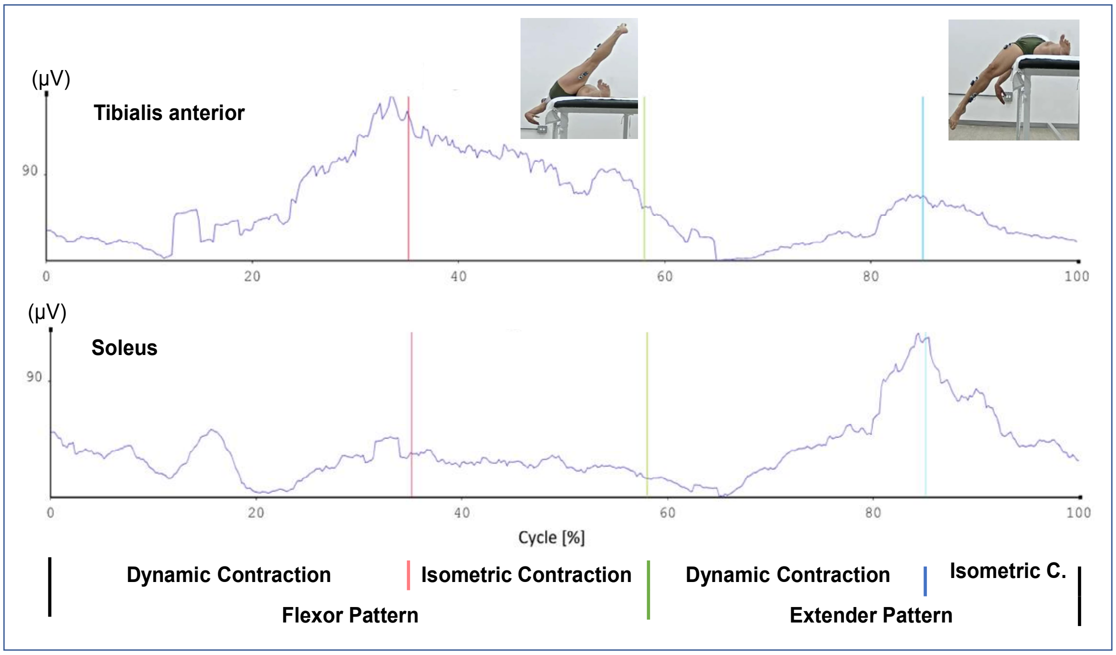

Fig. 2. Electromyographic tracing in dynamic and isometric phases, first Kabat diagonal, tibialis anterior and soleus muscles

The electromyographic tracing is exemplified with the tibialis anterior and soleus muscles of the first diagonal of Kabat. The figure shows the dynamic and isometric phases of the flexor pattern, followed by their counterparts in the extensor pattern. The first photograph shows the end of the flexor pattern in isometric contraction. The second photograph shows the end of the extensor pattern in isometric contraction.

2.6 Bias Control

The units of analysis were Physiotherapy students who knew the movement patterns described by Kabat and who were retrained for participation. The person who made the electromyographic records did not belong to the research team. The execution of the movement patterns was under the guidance of Master's students in Neurorehabilitation with a professional degree in physiotherapy and prior training and calibration. A commercial electromyograph and standardized laboratory procedures were used.

2.7 Statistical Analysis

The sociodemographic, functional and electromyographic characteristics for each muscle are described by univariate analysis. Error bars indicated the study variable by showing the eight muscles in each one of the movement patterns and by comparing both positions (Figs. 3 to 6). Most electromyographic records did exceed the assumption of normality ($p>0,05$), therefore the t Student test (parametric statistics) was applied to compare mean latency of the peak EMG activation between positions. Bilateral hypothesis tests were carried out at a confidence level of 95% ($p\leq0,05$). There was no data lost while processing and analyzing the data. The SPSS version 25.0 for Windows package (Statistical Package for the Social Science) was used for the analysis. Derived data supporting the findings of this study are available from the corresponding author on request.

3. RESULTS

Table 2 depicts the standard deviations and confidence intervals at 95% of the latency to peak EMG activation for each one of the muscles evaluated and for each one of the movement patterns. These are presented in percentage values, corresponding to the location within the movement pattern. The following is the analysis of each one of them.

Diagonal 1 – Flexor pattern: in supine position the average maximal muscle activation sequence occurred in the following order: soleus, femoral biceps, gluteus maximus, contralateral and ipsilateral spinal erector, tibialis anterior, rectus femoris and rectus abdominis (Fig. 2). Meanwhile in the standing position, the timing was: biceps femoris, gluteus maximus, contralateral spinal erector, soleus, ipsilateral spinal erector, tibialis anterior, rectus femoris, and rectus abdominis (Fig. 2). As noted, the maximum contraction sequence was identical for all muscles except for the soleus, which is the muscle that on average initiates the pattern in supine position, but is placed fourth in standing. The rectus abdominis closes the sequence in both patterns, while the tibialis anterior is located mainly at the end of the pattern, contrary to the normal timing known from distal-to-proximal. Significant differences were found in the mean latency of the gluteus maximus and biceps femoris ($p<0,05$; Table 2).

Diagonal 1 – Extensor pattern: in supine position the average maximal muscle activation sequence occurred in the following order: rectus femoris, contralateral and ipsilateral spinal erector, rectus abdominis, gluteus maximus, tibialis anterior, biceps femoris and soleus (Fig. 3). Meanwhile in the standing position, the timing was: rectus femoris, tibialis anterior, contralateral and ipsilateral spinal erector, gluteus maximus, soleus, rectus abdominis and biceps femoris. (Fig. 3). As noted, the sequence was similar in supine and standing positions with significant variations in mean latency of the biceps femoris and contralateral spinal erector ($p<0,05$; Table 2). Generally speaking, the contraction sequence occurred from proximal-to-distal.

Diagonal 2 - Flexor Pattern: in supine position the average maximal muscle activation sequence occurred in the following order: soleus, biceps femoris, contralateral spinal erector, rectus femoris, gluteus maximus, tibialis anterior, ipsilateral spinal erector and rectus abdominis (Fig. 4). Meanwhile in the standing position, the timing was: soleus, biceps femoris, contralateral spinal erector, tibialis anterior, gluteus maximus, ipsilateral spinal erector, rectus abdominis and rectus femoris (Fig. 4). As noted, the sequence was similar in supine and standing positions with differences in the intermediate pattern. Significant differences in mean latency for the rectus femoris and tibialis anterior ($p<0,05$ Table 2) were evident. The soleus initiates the sequence, meanwhile the rectus abdominis appears on average at the end of the pattern. This contradicts the normal timing known from distal-to-proximal.

Diagonal 2 – Extensor pattern: in supine position the average maximal muscle activation sequence occurred in the following order: gluteus maximus, tibialis anterior, rectus femoris, rectus abdominis, contralateral spinal erector, biceps femoris, ipsilateral spinal erector and soleus (Fig.

5). Meanwhile in standing position, the timing was: rectus femoris, tibialis anterior, ipsilateral spinal erector, gluteus maximus, rectus abdominis, contralateral spinal erector, biceps femoris and soleus (Fig. 5). As noted, the sequence was dissimilar in supine and standing positions with no clear sequence from proximal-to-distal or vice versa. The contraction of the tibialis anterior before the beginning of the pattern and soleus at the end, both in supine and standing positions is noteworthy. Significant differences were found in the mean latency for rectus femoris, biceps femoris and gluteus maximus (p<0,05; Table 2).

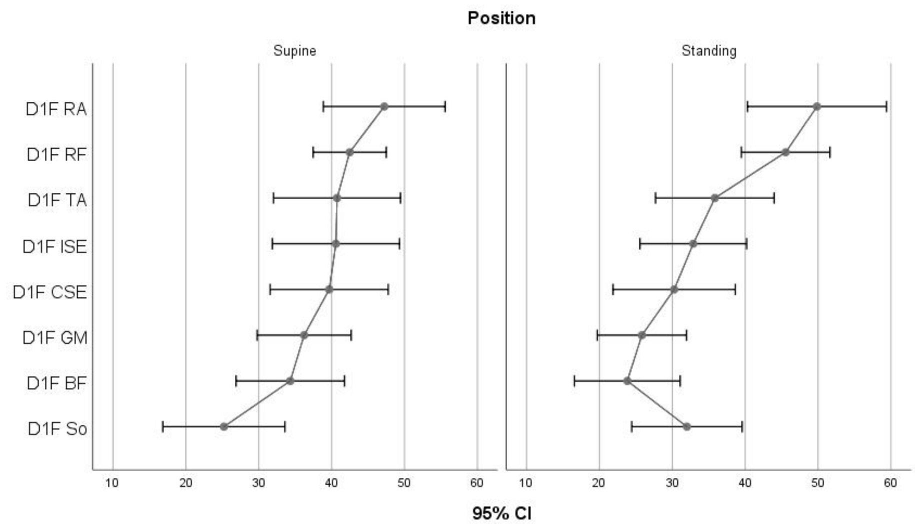

Fig. 3. First diagonal - flexor pattern: confidence intervals of the latency to peak EMG activation for each one of the muscles

Abbreviations. RA: Rectus Abdominis; RF; Rectus Femoris; TA: Tibialis Anterior; ISE: Ipsilateral Spinal Erector; CSE: Contralateral Spinal Erector; GM: Gluteus Maximus; BF: Biceps Femoris; So: Soleus

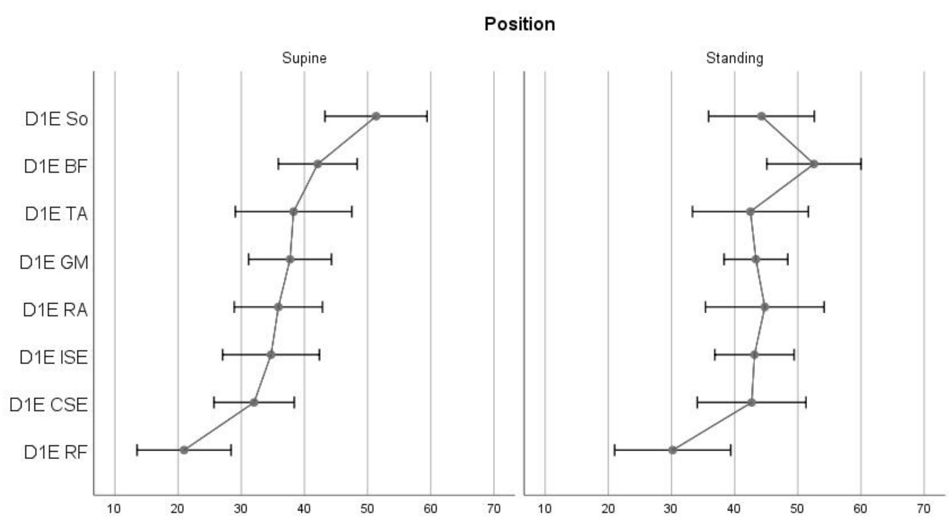

Fig. 4. First diagonal - extended pattern: confidence intervals of the latency to peak EMG activation for each one of the muscles

Abbreviations. So: Soleus; BF: Biceps Femoris; TA: Tibialis Anterior; GM: Gluteus Maximus; RA: Rectus Abdominis; ISE: Ipsilateral Spinal Erector; CSE: Contralateral Spinal Erector; RF; Rectus Femoris

Table 2. Latency to peak EMG activation in supine and standing positions (n=40)

Patter	Muscle	Supine		Standing		Test for equality of means		
		Mean (SD)	95% CI	Mean (SD)	95% CI	t	95% CI	Sig.
D1 Flexor	Rectus Abdominis	47 (26)	39 – 56	50 (30)	40 – 59	-0,42	-15,11 to 9,85	0,68
	Ipsilateral Spinal Erector	41 (27)	32 – 49	33 (23)	26 – 40	1,37	-3,50 to 18,92	0,18
	Contralateral Spinal Erector	40 (25)	32 – 48	30 (26)	22 – 39	1,63	-2,06 to 20,89	0,11
	Gluteus Maximus	36 (20)	30 – 43	26 (19)	20 – 32	2,37	1,64 to 19,16	0,02*
	Rectus Femoris	42 (16)	37 – 48	46 (19)	39 – 52	-0,79	-10,84 to 4,68	0,43
	Biceps Femoris	34 (23)	27 – 42	24 (23)	17 – 31	2,04	0,27 to 20,73	0,04*
	Tibialis Anterior	41 (27)	32 – 49	36 (25)	28 – 44	0,83	-6,83 to 16,64	0,41
	Soleus	25 (26)	17 – 34	32 (24)	24 – 40	-1,22	-17,90 to 4,33	0,23
D1 Extender	Rectus Abdominis	36 (22)	29 – 43	45 (29)	35 – 54	-1,54	-20,41 to 2,61	0,13
	Ipsilateral Spinal Erector	35 (24)	27 – 42	43 (20)	37 – 49	-1,72	-18,17 to 1,32	0,09
	Contralateral Spinal Erector	32 (20)	26 – 38	43 (27)	34 – 51	-2,02	-21,19 to -0,14	0,05*
	Gluteus Maximus	38 (21)	31 – 44	43 (16)	38 – 48	-1,38	-13,79 to 2,50	0,17
	Rectus Femoris	21 (23)	14 – 28	30 (29)	21 – 39	-1,58	-20,88 to 2,39	0,12
	Biceps Femoris	42 (20)	36 – 48	53 (23)	45 – 60	-2,17	-20,02 to -0,87	0,03*
	Tibialis Anterior	38 (29)	29 – 47	42 (29)	33 – 52	-0,66	-17,01 to 8,58	0,51
	Soleus	51 (25)	43 – 59	44 (26)	36 – 53	1,23	-4,35 to 18,53	0,22
D2 Flexor	Rectus Abdominis	49 (24)	42 – 57	45 (30)	35 – 55	0,70	-7,92 to 16,49	0,49
	Ipsilateral Spinal Erector	45 (23)	38 – 53	42 (28)	33 – 51	0,61	-7,80 to 14,73	0,54
	Contralateral Spinal Erector	35 (28)	26 – 44	29 (27)	20 – 38	1,03	-5,95 to 18,74	0,31
	Gluteus Maximus	40 (25)	32 – 48	37 (24)	30 – 45	0,42	-8,46 to 13,04	0,67
	Rectus Femoris	39 (23)	31 – 46	52 (20)	46 – 58	-2,77	-22,63 to -3,72	0,01*
	Biceps Femoris	28 (22)	21 – 35	27 (25)	19 – 35	0,30	-8,86 to 12,05	0,76
	Tibialis Anterior	44 (22)	37 – 51	32 (21)	26 – 39	2,45	2,19 to 21,21	0,02*
	Soleus	27 (25)	19 – 35	18 (24)	10 – 26	1,62	-2,06 to 19,79	0,11
D2 Extender	Rectus Abdominis	34 (30)	25 – 44	43 (29)	34 – 52	-1,41	-22,24 to 3,83	0,16
	Ipsilateral Spinal Erector	42 (26)	34 – 50	37 (27)	29 – 46	0,82	-6,93 to 16,60	0,42
	Contralateral Spinal Erector	37 (30)	28 – 47	48 (28)	39 – 57	-1,62	-23,51 to 2,44	0,11
	Gluteus Maximus	28 (17)	23 – 34	42 (25)	34 – 50	-2,91	-23,12 to -4,33	0,01*
	Rectus Femoris	33 (28)	24 – 42	16 (22)	9 – 23	3,05	5,98 to 28,41	0,01*
	Biceps Femoris	39 (20)	32 – 45	50 (18)	44 – 56	-2,72	-19,96 to -3,07	0,01*
	Tibialis Anterior	29 (31)	19 – 39	32 (25)	23 – 40	-0,45	-15,32 to 9,71	0,66
	Soleus	47 (25)	39 – 55	54 (19)	48 – 60	-1,49	-17,12 to 2,48	0,14

*Values correspond to location within the movement pattern, on a scale of 0 to 100%. Abbreviations. D1: first diagonal; D2: second diagonal; SD: standard deviation; IQR: interquartile range; t: Student test; Sig: bilateral asymptotic significance. * Significant difference. D1 Flexor: hip in flexion, adduction and lateral rotation; knee in extension; ankle in dorsiflexion and inversion. D1 Extensor: hip in extension, abduction and medial rotation; knee in extension; ankle in plantar flexion and eversion. D2 Flexor: hip in flexion, abduction and medial rotation; knee in extension; ankle in dorsiflexion and eversion. D2 Extensor: hip in extension, adduction and lateral rotation; knee in extension; ankle in plantar flexion and inversion.*

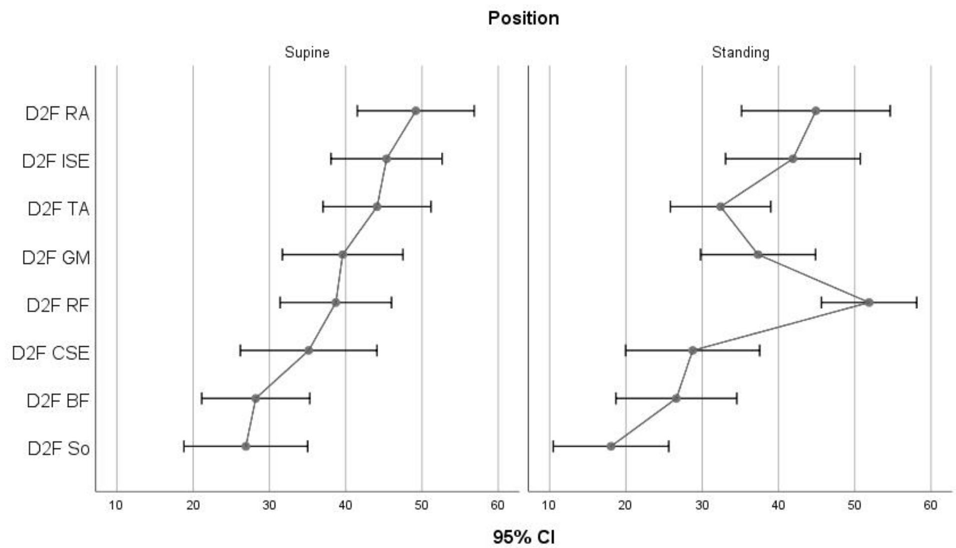

Fig. 5. Second diagonal - flexor pattern: confidence intervals of the latency to peak EMG activation for each one of the muscles

Abbreviations. RA: Rectus Abdominis; ISE: Ipsilateral Spinal Erector; TA: Tibialis Anterior; GM: Gluteus Maximus; RF: Rectus Femoris; CSE: Contralateral Spinal Erector; BF: Biceps Femoris; So: Soleus

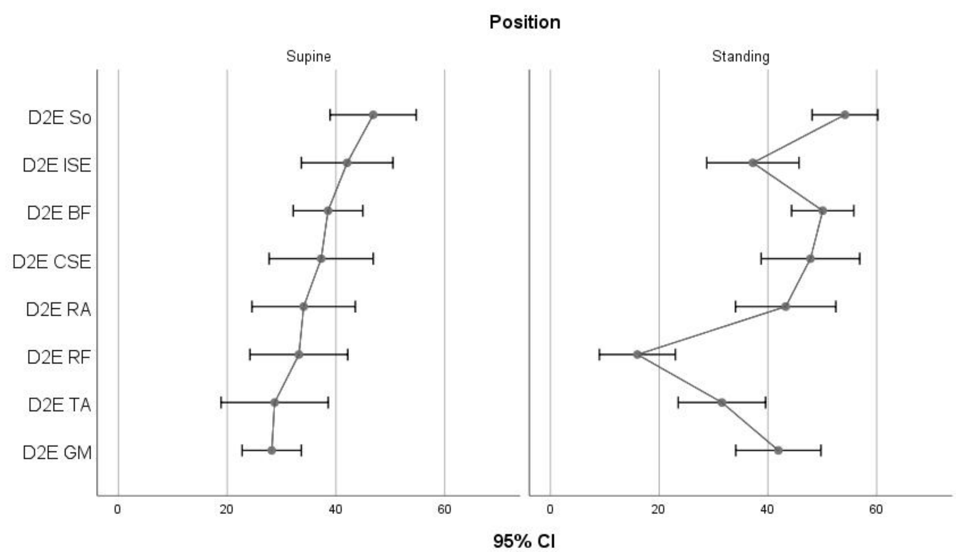

Fig. 6. Second diagonal - extended pattern: confidence intervals of the latency to peak EMG activation for each one of the muscles

Abbreviations. So: Soleus; ISE: Ipsilateral Spinal Erector; BF: Biceps Femoris; CSE: Contralateral Spinal Erector; RA: Rectus Abdominis; RF; Rectus Femoris; TA: Tibialis Anterior; GM: Gluteus Maximus

4. DISCUSSION

This study, aimed at determining the sequence of muscle contractions during their execution in supine and standing positions of the lower limb movement patterns described by Kabat. It was based on the electromyographic measurement of the latency to peak EMG activation. The variable results suggest that a clearly defined sequence is not followed in distal-to-proximal or proximal-to-distal sequence, although there is a greater trend towards the latter. With regards to the comparison between positions, there is a tendency for the sequence to be presented in the same way, independently of the position. The findings show statistically significant differences in only three muscles for each one of the patterns, which represents a small number with respect to the eight muscles evaluated.

From the muscle contraction sequence, it is worth clarifying that the latency to peak EMG activation is indicative of the time when the muscle expressed its maximum activation throughout the execution of the pattern and this does not necessarily coincide with its onset. This is important when considering that the eight evaluated muscles showed their activation at different magnitudes throughout the pattern path, even from the onset, making differentiation impossible.

This could be attributed to the processes of organization of the movement from which, for example, the intentionality of executing a movement is sufficient to generate mechanisms of anticipation that lead to muscle preparation and the onset of agonist-antagonistic coordination. It persists in the performance of movement, facilitated by the nervous system in order to control the torque exerted on the joints involved and provide a mechanical link between the segments of the moving body and the required support of the environment [14].

However, overlapping muscle contractions, considering that muscles move across their entire contraction range [7], support the presence of agonist-antagonist muscle activity throughout the pattern path, with different degrees of intensity in the EMG signal. This behavior can also be identified in the analysis of the latency to peak EMG activation, which is variable in this study, where an overlap of the confidence intervals of the means is observed (Figs 1 to 4).

Considering then the latency to peak EMG activation and not the onset of muscle activity for the determination of the sequence, these results support the assumption under which muscle activity patterns vary substantially between movements and include multiple strategies that increase the working capacity of muscles [14]. In turn, they contrast with the theory that normal timing occurs in strictly distal-to-proximal or proximal-to-distal sequences, being clear that one or the other sequence depends on the purpose of the movement, as reported in literature [15].

In children, during their first months of development, the coordination and sequence of movement proceeds proximal-to-distal sequence and as they mature, around eleven months when they begin to stand independently, a distal-to-proximal muscle activation response is observed more consistently, although still immature [16].

Therefore, in adults, the normal timing of most coordinated and efficient movements has been described from distal-to-proximal sequence, being the activities of the upper limb an example when matured in the gripping activity, with the hand directing the course of the arm movements. For its part, in the case of the activity of the lower limbs, it is the small movements that start in the foot and proceed towards the hip that will allow adults to maintain balance in a standing position [9,17]. In light of the above, there is controversy as investigations such as Kazemi's have shown conflicting results [18].

Other authors claim that there is a wide variety of movement patterns occurring in a proximal-to-distal sequence for both the upper and lower limbs [19-20]. As for the latter, as found by Bobbert (1988) and Putnam (1993), cited by Danion, this sequence has been demonstrated in activities such as kicking a ball and jumping, which according to this author is explained as the product of biomechanical principles of maximizing kinetic energy and transmission of impulses from one segment to another [10].

As opposed to the consideration of a sequence of movement in distal-to-proximal sequence, as described in the Kabat method within the framework of the diagonals, it is important to start off with the assumption that first an activity at central level must occur in order to foster stability, existing, for example, a foreseen muscular activity of the trunk and the hip during the action to move the contralateral leg forwards [17]. However, the anticipatory axial activation would not be considered within the normal timing if understood as the sequence of solely dynamic muscle contractions [2].

Despite the lack of consensus, few studies have been oriented to validate normal timing specifically in the patterns described by Kabat, although authors have worked on the analysis of gestures similar to these, with characteristics clearly different from those of this research. As an example, it is the intentionality beyond the fact of executing the pattern, giving meaning to the exercise within the framework of a situation-task and in most cases, mediated by motor learning processes in which the specific gesture is part of the skills and abilities of the participant.

The kick executed during soccer practice, very similar to the flexor pattern of diagonal 1 described by Kabat, is an example of a pattern of movement that has been studied as part of a sporting gesture, being analyzed from biomechanical characteristics such as kinetics, kinematics, muscle activation patterns, among others. Findings such as those of Proft et al (1988) cited by Kellis show that a sequence of muscle activation from proximal-to-distal is not evident [21], although they do not claim the opposite. However, the idea that there is simultaneous activation of a significant number of muscles (with antagonistic actions) that offer stability, losing the effectiveness (power) of movement.

For their part, in the analysis of muscle activation patterns in a handball throw practice, Tillaar and Ettema analyzed the existence of a proximal-to-distal sequence in the timing of upper and lower limbs, observing a proximal-to-distal temporal sequence only for the onset of joint movements [22]. These results were subsequently confirmed by Serrien, through a systematic review and meta-analysis that concludes that the onset of angular velocities follows a strict sequence from proximal-to-distal, while, for maximum velocities, the sequence can be reversed [23].

In contrast, Liu et al, in analyzing the sequence of movements of upper and lower limbs during javelin throwing, demonstrated a sequence of movements that did not follow a proximal-to-distal sequence. Statistically significant differences in sequences were present among participants of different sexes [24].

Mirzaie et al, during the execution of two functional tasks in the standing position, evaluated the muscle recruitment patterns of the hip and knee in healthy subjects with some health conditions. In healthy subjects, the recruiting pattern was medium gluteus followed by vast oblique medial, vast lateral and maximus gluteus. Results suggest early activation at the gluteus level (in the frontal plane) to stabilize the proximal area and maintain proper alignment [25]. However, the delayed activation in the sagittal plane at the hip level suggests variations in the recruitment sequences according to the plane of movement and the specific demands of the task.

Ashford et at, on the other hand, in their study of the timing during the transition seated-standing and standing-seated positions, through an electromyographic analysis of the muscle activity of lower limbs in participants who did not have any previous health conditions, demonstrated a degree of partial consistency in the sequences of muscle activity, with evident variations in some subjects for most of the muscles evaluated, suggesting differences within the limits of “normality” [26].

These results, in the light of the present study, allow us to conclude the presence of variability in the presentation of the sequences of muscle activation considering multifactorial influences like the degrees of freedom, the speed of execution, the knowledge of the pattern and / or the intentionality that its execution mediates, among others. This hinders standardization of a sequence of movements and to define it as “normal”.

In this way, the theory of normal timing is partially contradicted which posits that the sequence of muscle contractions is performed distal-to-proximal, especially at the level of the limbs; considering variability in timing and even a greater tendency to a proximal-to-distal sequence.

In this study, although the participants, physiotherapy students, knew the movement patterns described by Kabat and were additionally re-trained for participation, an adequate level of automation may not be achieved, which could mean variations and / or delays in the muscle activation sequence, exacerbated by the fact that each one of the participants became aware of all the components of the pattern. This situation is attenuated by some kind of proprioceptive feedback, as suggested in the facilitation techniques.

In this sense, it is recommended that the use of movement patterns within the framework of therapeutics should always be under the mediation of an expert-led facilitation technique, since proprioceptive feedback ensures a certain timing, in line with the objectives of the therapist and the user, which cannot be controlled with mere instruction or, otherwise, to be taught in the context of the execution of a functional task or activity and not as part of an active exercise to freedom.

Likewise, the variability found in muscle activation sequences (timing) suggests the need to address the individual characteristics of each subject and the task for which a particular pattern is required, considering a qualitative assessment in quality, rhythm, coordination, among other aspects of movement, which is the ultimate result of the generation of efficient muscle contractions beyond a specific sequence.

5. CONCLUSIÓN

These results partially contradict the theory of normal timing that postulates that the sequence of muscle contractions is performed from distal to proximal. Future studies should include a greater number of muscles and assess other variables such as the first contraction evidenced in the electromyographic tracing.

6. LIMITATIONS AND RECOMMENDATIONS

The use of eight-channel equipment limited the scanning of a greater number of lower limb muscles. Further studies will be able to perform maximum resistance in the entire trajectory of the movement pattern in dynamic contraction, which would help clarify their sequence of contractions or normal timing. Likewise, investigations may be carried out to determine the sequence of upper limb contractions.

The variable used in our study, should be complemented by the first contraction evidenced in the electromyographic path, which would lead to more conclusive results on normal timing in lower limbs. Future studies may assess the first contraction using early detection algorithms such as the threshold-based onset detection method [27].

ETHICAL APPROVAL

This study was approved by the bioethics committee of the Universidad Autónoma de Manizales, Colombia (act 079 of 2018) and was conducted between august 2018 and october 2019. It complies with the principles established in the declaration of Helsinki of the World Medical Association. The guidelines of resolution 8430 of 1993 of the Colombian Ministry of Health that establishes the scientific, technical and administrative standards for health research were followed.

CONSENT

As per international standard or university standard, participants' written consent has been collected and preserved by the authors.

ACKNOWLEDGMENTS

The authors express our thanks to the participants in the study and to the students of the Master in Neurorehabilitation of Universidad Autónoma de Manizales (UAM), Cohort IX: Angélica Irene López, Karen Vanessa Mercado, Lizeth Paola Valencia, Lisa Fernanda Molina, Erika Viviana Contreras, Diana Alejandra Orjuela, María Natalia Alava, Diana Lorena Cárdenas, Leidy Catalina Burbano, Evelyn Patricia Galarraga and Edwin Luis Levano. Likewise, to the students of Physical Therapy of UAM Camila Rodríguez and Sareli Suárez, the biomedical engineer Daniela López from the Movement Analysis Laboratory of UAM (Colombia), and the biomedical enginner Daniela Vorazzo from BTS Bioengineering (Italy).

The authors express their gratitude to Mónica Naranjo and Alice James of the Languages Institute, Universidad Autónoma de Manizales (Colombia), for translating and reviewing this final manuscript into English.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Available:https://doi.org/10.1155/S1110865701000191

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle4.com/review-history/71792