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Jacobs Journal of Sports Medicine

OPEN ACCESS

Research article

Muscle Activity, Pain and Resistance Onsets during the Slump Test in Hamstring Injured Athletes

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Received: 06-09-2016

Accepted: 09-27-2016

Published: 12-12-2016

Abstract

Objective: To determine muscle activity, pain and resistance onsets during the slump test in professional and semi-professional rugby union players with clinically diagnosed hamstring strains.

Study Design: Cross sectional, observational.

Setting: Laboratory setting.

Participants: Ten male rugby union players (age 24.9±3.35 years) with clinically diagnosed hamstring strains.

Main Outcome Measures: Surface electromyography recorded the onset of biceps femoris ($M1_{BF}$) and semitendinosus ($M1_{ST}$) activation, whilst light-emitting triggers activated by the participant and examiner respectively recorded onset of symptoms (P1) and onset of resistance (R1) respectively, during the slump test, on both limbs, with cervical flexion and extension. Two-way ANOVA examined the effect of cervical spine position and injury on the knee angle corresponding to muscle activity, pain and resistance onsets and the level of significance was set at $p<0.05$.

Results: Cervical spine position had a significant effect on the range of knee extension at which all four variables occurred during the slump test ($M1_{BF}$, $p=0.004$; $M1_{ST}$, $p=0.024$; P1, $p=0.008$; R1, $p=0.001$) whilst injury had no significant effect ($p<0.05$).

Conclusions: Structural differentiation has a significant effect on knee angle corresponding to muscle, pain and resistance onsets during the slump test in posterior thigh injured athletes.

Highlights

Structural differentiation affects measurements taken in neurodynamic tests.

Injury has no effect on measurements taken in neurodynamic tests.

Keywords: Slump Test; Hamstring Injury; Structural Differentiation; Athletes

Abbreviations

P1: Onset of Pain/symptoms;
R1:Onset of Resistance as determined by the examiner;

M1: Onset of Muscle activity;
M1BF: Onset of Muscle activity of Biceps Femoris muscle;
M1ST: Onset of Muscle activity of Semitendinosus muscle;
EMG: Electromyography;
SLR: Straight Leg Raise;
CF: Cervical Flexion;
CE: Cervical Extension;
CCSF: Contralateral Cervical Side Flexion;
SD: Standard Deviation;
ICC: Intraclass Correlation Coefficient;
SEM: Standard Error of Measurement;
SDD: Smallest Detectable Difference

Introduction

Neurodynamic testing has become a common feature of musculoskeletal assessment with structural differentiation being an integral part of these tests. Structural differentiation involves moving the neural structure in the area in question, without moving the musculoskeletal tissues in the same region, thereby enabling a clinician to differentiate between neurogenic symptoms and those of musculoskeletal origin [1]. The subjective reporting of pain onset (P1), onset of resistance as determined by the examiner (R1) and onset of local muscle activity are proposed as end points to use during neurodynamic tests [2-5] and can be affected by structural differentiation [2,5,6].

Lew and Briggs[7] reported significant decreases in posterior thigh pain when cervical flexion was released during the slump test, whilst van der Heide et al [5] discovered onset of pain to occur earlier with structural differentiation during elbow extension in an upper limb neurodynamic test. Herrington et al.[6] meanwhile, cited onset of resistance (R1) as determined by the examiner, to occur significantly earlier in range of knee extension during the slump test with cervical flexion than extension. Earlier distal muscle activation was discovered by Boyd et al.[8] during the straight leg raise (SLR) with ankle dorsi-flexion, compared to plantar-flexion. During a neural tissue provocation test with median nerve bias, Van der Heide et al. [5] reported onset of trapezius activity to occur earlier during elbow extension with structural differentiation (contralateral cervical side flexion). The aforementioned research [5-8] has demonstrated that structural differentiation causes an earlier onset of muscle activity, pain and resistance during neurodynamic testing; however, this research has evaluated only one or two of these responses during a neurodynamic test; not all three simultaneously.

The slump test is regarded as a vital diagnostic tool for patients with suspected hamstring strain particularly considering mechanosensitivity of the sciatic nerve, measured via the slump test, was discovered in 57% of rugby union players [9]. Due to the intimate anatomical relationship between the sciatic nerve and hamstring muscles, the aforementioned authors concluded that sciatic nerve mechanosensitivity may play a significant role in hamstring injury occurrence or recurrence. McHugh, Johnson, & Morrison [10] echoes this sentiment stating that adverse neural tension may be a contributing factor in recurrent hamstring strains having discovered significantly increased passive resistance to hamstring stretch, absent of any meaningful electromyography activity, to occur during hamstring stretches with cervical and thoracic flexion.

No research to date has evaluated the effect structural differentiation has on muscle activity, pain and resistance onsets simultaneously during the slump test in healthy or pathological individuals. It is important for clinicians to understand the effect cervical flexion has on these variables during the slump test, as they are cited in literature as the end points for clinicians or researchers to use, when conducting neurodynamic tests [2-5]. Therefore, the aim of this study is to evaluate muscle activity, pain and resistance onsets during the slump test in professional and semi-professional rugby union players with clinically diagnosed hamstring strains.

Method

Participants

A total of ten male participants volunteered to participate in this study. The mean age of this cohort at the time of testing was 24.9±3.35 years (range 20-31 years) and the average length of time from injury occurrence to testing was 18.8±6.3 days (range 13-30 days). Participants met the inclusion criteria if they were over 18 years of age, competed at a semi-professional or professional level in rugby union in the United Kingdom, had sustained a hamstring strain as diagnosed by a member of the medical team at their respective club and had currently not returned to competition. Participants were excluded if they reported alternative current injuries, had returned to competition or had undergone surgery or sustained major trauma to the lumbar, hip, gluteal or posterior thigh regions.

The diagnosis of each hamstring injury was entirely dependent upon the diagnostic capabilities of the medical staff (physiotherapist/sports rehabilitator and club doctor) at the participating clubs where the diagnosis was initially made, with no participant undergoing radiological investigation to verify the injury. All medical staff that completed the assessments had a minimum 6 years of musculoskeletal experience in rugby union. The clinicians were requested to adhere to three key clinical elements associated with hamstring injury which were; decreased isometric strength with or without pain as measured using a manual isometric contraction by the clinician, decreased range of motion via passive straight leg raise test (hip flexion with knee extension) and finally, pain on palpation of the suspected site of injury [11]; criteria also utilised in Turl and George's [9] research. All the participating medical staff reported each of these findings for posterior thigh injury to occur in all participants. Ethical approval was obtained from the local ethics committee, following which, informed consent was obtained from all participants. This study was carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

Experimental Protocol

Simultaneous recordings of the surface electromyography (EMG) activity from the Biceps Femoris and Semitendinosus muscles were recorded using a portable EMG system (Noraxon MyoTrace 400 Master Edition). A default sampling frequency of 1004Hz was used for surface EMG data acquisition and a high and low pass filter between 10 and 500 Hz respectively was utilised and the signal preamplified (x1000). To reduce electrode-skin impedance, the skin on the posterior thigh surface was initially shaved before being exfoliated by light abrasion (Nuprep, SLE Ltd) and then cleaned using alcohol swabs. One pre-gelled, self-adhesive silver-silver chloride dual snap electrodes, with a centre to centre distance of 2cm (Noraxon Dual Electrodes), were placed in a line parallel to the respective muscle fibers of the Biceps Femoris and Semitendinosous, in between the nearest innervation zone and musculotendinous junction Guidelines [12]. A single ground electrode (Noraxon Single electrode), was placed at the lateral epicondyle of the femur. The electrode for Biceps Femoris was placed parallel to the muscle fibers, on the lateral aspect of the thigh, two-thirds the distance from the greater trochanter of the femur and popliteal fossa [12]. For Semitendinosus, the electrodes were placed on the medial aspect of the thigh, approximately 3cm in from the lateral border of the thigh and approximately half the distance from the gluteal fold to the popliteal fossa [12]. Muscle activity via the electrodes, was confirmed by contracting the hamstring muscles using a manual muscle test of knee flexion by the examiner. The subject sat on a plinth with thighs fully supported, knees together and the popliteal fossa against the edge of the table. The subject was holding the sacrum in a vertical position, the subject allowed the trunk to sag towards the hips [6]. A strap was then placed across the shoulders below C7 vertebra and anchored under the plinth, to ensure constant overpressure of thoraco-lumbar flexion. The cervical spine was then moved, in randomised test order, into either flexion or extension. The subject was requested to look at the ceiling for cervical extension, and to bring chin to chest for cervical flexion; the latter of which the examiner applied overpressure to. In this position, the examiner then applied maximum dorsi-flexion to the ankle before extending the knee to the point of either terminal knee extension if the subject was symptom free at that point or the maximum sensation the subject could tolerate. The examiner was an experienced musculoskeletal therapist with over ten years of clinical experience. The limb was moved at a constant velocity through use of a metronome.

The outcome variables measured during the slump test were; onset of resistance experienced by the examiner (R1), onset of symptoms as experienced by the subject (P1) and onset of muscle activity for the Biceps Femoris ($M1_{BF}$); and Semitendinosus ($M1_{ST}$) muscles. All of these variables were measured with respect to the knee angle achieved during the slump. Onset of resistance (R1) was defined as the point where the examiner determines resistance to the movement [1] whilst onset of symptoms (P1) was defined as the moment when the least experience of pain symptoms or sensations is recognised by the subject [3]. Onset of muscle activity (M1) was regarded as the first point where the EMG signal exceeded a threshold level of 3 standard deviations (SD) above the mean baseline [13].

Two triggers were attached to the EMG system both which upon activation emitted a light in addition to registering a mark on their own separate channels of the EMG data acquisition system. The slump test was then conducted on both legs of the hamstring injured subjects. Upon experiencing the onset of symptoms (P1), the subject activated their hand held trigger whilst the examiner activated a trigger, via a footswitch, upon feeling the onset of resistance (R1) during the slump test (Figure 1). Three trials were conducted for both cervical flexion and extension positions for each hamstring injured subject. The mean of the three trials was used for subsequent analysis. The entire slump test was recorded via video camera (Sony Digital Video Camera Recorder), placed in the sagittal plane to the slump test, to the limb. The range of knee extension was later analysed via computer software and full knee extension equated to 0°.

Figure 1. The slump test with cervical flexion. The examiner activates a foot trigger upon feeling resistance onset (R1) whilst the patient activates a hand-held trigger for onset of symptoms (P1) during the cervical flexion component of the slump test as the knee is being passively moved into extension. Full knee extension equated to 0°

The raw EMG data was exported as ASCII files and subsequently analysed using a specifically constructed computer algorithm (Testpoint V7 Measurement Computing Corporation, Norton, MA 02766, USA). Prior to analysis, the raw EMG data was full-wave rectified and filtered using a low pass filter of 100Hz. Onset of muscle activity (M1) was determined using the computer algorithm following which, the EMG data was visually inspected by the examiner to verify the muscle onsets[13, 14]. The onset time of M1, P1 and R1 was computed and recorded for all subjects and the corresponding knee angle for each of these times were subsequently calculated using Quintic Biomechanics (version 11, Quintic Consultancy Ltd). To calculate the knee angle corresponding to muscle onsets, firstly the knee angle correlating to the onset of resistance experienced by the examiner was determined by inspection of the recordings by the cameras, using Quintic Biomechanics (version 11). The light emitting trigger identified the point where R1 occurred, allowing the examiner to capture the specific frame when the

Triggers illuminated, and therefore determine the time difference between the onset of the movement of knee extension during the slump test and R1. Referring back to the onset times for the muscles which were determined previously from Testpoint, the time from movement onset to muscle onsets was then

computed. Once these values were obtained, Quintic enabled the corresponding knee angle for each variable to be calculated, by using the anatomical landmarks of the greater trochanter of the femur, lateral femoral epicondyle and the lateral malleolus.

Statistical Analysis

A Two way ANOVA (SPSS version 22.0) was utilised to examine the effect of cervical spine position and injury, on the knee angle corresponding to muscle, pain and resistance onsets during the slump test in hamstring injured athletes (factors – spine position and injury, dependant variables – knee angle at pain, resistance onset and EMG onset for either semitendinosus or biceps femoris). Differences between limbs during neurodynamic testing to determine if mechanosensitivity is present [15]. The alpha level for statistical significance was set at $\alpha<0.05$.

Reliability

To determine the within session reliability for knee angle corresponding to onset of resistance (R1), onset of symptoms (P1) and onset of biceps femoris ($M1_{BF}$) and semitendinosus ($M1_{ST}$), Intraclass Correlation Coefficient ($ICC_{3,1}$), Standard Error of Measurement (SEM) and Smallest Detectable Difference (SDD) were calculated using the three trials recorded for these variables during cervical flexion and extension in the injured and uninjured limbs; the findings of which can be viewed in Tables 1 and 2. Coppieters et al.[3] reported ICC values between 0.70 and 0.90 as "good" whilst above 0.90 was deemed excellent.

An ICC between 0.40 and 0.70 was regarded by the same authors as "fair". On the whole, good or excellent ICC results were achieved in this study for the majority of variables.

	Neurodynamic Test	ICC	SEM	SDD
Onset of muscle activity (M1) of Biceps Femoris	Slump test + CF	0.78	5.4°	14.9°
	Slump test + CE	0.77	2.2°	6.1°
Onset of muscle activity (M1) of Semitendinosus	Slump test + CF	0.85	6.1°	17.0°
	Slump test + CE	0.79	2.2°	6.0 °
Onset of symptoms (P1)	Slump test + CF	0.90	3.6°	10.1°
	Slump test + CE	0.60	2.6°	7.1°
Onset of resistance (R1)	Slump test + CF	0.95	3.5°	9.7°
	Slump test + CE	0.90	2.6°	7.3°

"ICC"=Intraclass Correlation Coefficients; "SEM"=Standard error of measurement; "SDD"= smallest detectable difference; "CF"=cervical flexion; "CE"=cervical extension

Table 1. The within session intra-rater reliability of detecting onset of resistance, pain and muscle activity of biceps femoris and semitendinosus, with respect to knee angle (degrees), during the slump test for cervical flexion and extension in the injured limb.

	Neurodynamic Test	ICC	SEM	SDD
Onset of muscle activity (M1) of Biceps Femoris	Slump test + CF	0.98	3.2°	9.0°
	Slump test + CE	0.61	2.8°	7.8°
Onset of muscle activity (M1) of Semitendinosus	Slump test + CF	0.74	2.6°	7.2°
	Slump test + CE	0.70	3.0°	8.3°
Onset of symptoms (P1)	Slump test + CF	0.60	1.9°	5.2°
	Slump test + CE	0.72	2.2°	6.0°
Onset of resistance (R1)	Slump test + CF	0.65	2.1°	5.9°
	Slump test + CE	0.72	1.6°	4.5°

"ICC"=Intraclass Correlation Coefficients; "SEM"=Standard error of measurement; "SDD"= smallest detectable difference; "CF"=cervical flexion; "CE"=cervical extension

Table 2. The within session intra-rater reliability of detecting onset of resistance, pain and muscle activity of biceps femoris and semitendinosus, with respect to knee angle (degrees), during the slump test for cervical flexion and extension in the uninjured limb.

Results

Cervical spine position was discovered to significantly influence the range of knee extension at which all four variables occurred during the slump test ($M1_{BF}$, p=0.004 power=0.93; $M1_{ST}$, p=0.024; power=0.70; P1, p=0.008; power=0.87; R1, p=0.001; power=0.98). Injury was found to have no significant effect on the onset of biceps femoris (p=0.184), semitendinosus (p=0.85), pain (p=0.636) and resistance (p=0.904) during the slump test. The mean (± standard error of mean) knee angle obtained in the injured and uninjured limbs during both cervical spine positions of the slump test can be viewed in Table 3.

	Mean knee angle (degrees)			
	Cervical flexion		Cervical extension	
	Injured limb	Uninjured limb	Injured limb	Uninjured limb
Onset of Biceps femoris activity	39.5±5.4°	32.7±3.2°	24.3±2.2°	20.2±2.8°
Onset of Semitendinosus activity	31.6±6.1°	29.6±.2.6°	19.6±2.2°	19.9±3.0°
Onset of symptoms	23.5±3.6°	23.6±1.9°	16.1±2.6°	15.2±2.2°
Onset of resistance	21.6±3.5°	19.8±2.1°	13.1±2.6°	14.3±1.6°

Table 3. Mean knee angle (degrees) (± Standard error of mean) corresponding to the onset of biceps femoris and semitendinosus muscle activity, pain and resistance (degrees) during the slump test with cervical flexion and extension in male rugby union players (n=10) with a clinically diagnosed hamstring strain (Full knee extension=0°).

Discussion

The aim of this study was to evaluate the onset of muscle activity, pain and resistance during the slump test in athletes with clinically diagnosed hamstring strains. Structural differentiation by means of altering the cervical spine position had a significant effect ($p<0.05$) on the onset of muscle activity, pain and resistance during the slump test, whilst injury had no statistically significant effect ($p>0.05$) on these variables. Due to the mean time from injury to testing being 18.8 days, a time point where often athletes have often returned to competition following hamstring injury, it is perhaps unsurprising that injury had no significant effect on the onset of muscle activity, pain and resistance during the slump test in this study. Structural differentiation, via cervical flexion however, caused $M1_{BF}$, $M1_{ST}$, P1 and R1 to occur significantly earlier in range of knee extension during the slump test in this study; a finding in agreement with previous research who report structural differentiation to cause the measurements typically taken during neurodynamic tests to occur significantly earlier in the range of the moving joint[5, 6, 16].

Cervical flexion resulted in the onset of symptoms (P1) to occur significantly earlier during the slump test in this study, a finding similar to Boyd et al.[8], who reported structural differentiation (ankle dorsi-flexion) during the straight leg raise (SLR) to cause a reduction in hip joint range of motion at the point of

the individual citing onset of pain. The aforementioned authors also discovered that range of motion of the hip at the point of maximally tolerated symptoms was significantly decreased during the SLR with ankle dorsi-flexion. Despite being an upper quadrant neurodynamic test, similar findings were echoed in van der Heide et al's [5] research as the onset of pain occurred significantly earlier as a result of structural differentiation (contralateral cervical side flexion (CCSF)) than when the spine was in a neutral position.

The earlier onset of symptoms as a consequence of cervical flexion during the slump test in this study, may be due to the effect this manoeuvre has on the neural tissues of the body. Joint movements, such as which occurs during neurodynamic testing, cause alterations in strain and excursion throughout a nerve [17]. Increases in strain and excursion within a nerve have been reported to occur during upper and lower limb neurodynamic tests [18-20]. In early cadaveric work, Inman and Saunders [20] discovered cervical, trunk and hip flexion individually, caused migration of the cervical, thoracic and lumbar nerve segments of varying magnitude, whilst Coppieters et al [18] noted significant proximal excursion of the sural nerve towards the hip joint during a modified SLR. Dilley et al [19] discovered that even moving a joint as remote as the cervical spine, caused increases in strain in the median nerve in the forearm. It is therefore feasible that maintaining the head, trunk and hip in a flexed position, in addition to the ankle being placed in dorsi-flexion, whilst applying knee extension (i.e. the slump test), will induce increased tension along the spinal cord and lower limb peripheral nerves, thereby potentially provoking an increase in symptoms in a patient, with perhaps an early onset of symptoms during the test.

Structural differentiation during the slump test caused a significant decrease ($p<0.05$) in the knee angle corresponding to biceps femoris and semitendinosus activation onsets in this study. van der Heide et al. [5] cited similar findings in an upper limb neurodynamic test, with onset of trapezius muscle activity occurring significantly earlier during elbow range or motion, when contralateral cervical spine side flexion was the structurally differentiating manoeuvre. Balster & Jull [2] reported muscle activity to continually increase with each successive stage of a neurodynamic test for the upper limb whilst Boyd et al.[8] discovered the number of muscles activated between the onset of pain and maximum tolerated pain, increased during the SLR with varying ankle positions. The aforementioned authors promoted the theory of the muscular system acting as a protective mechanism for the nervous system, which may be occurring in the injured athletes in this study. The reason why flexing a joint as remote as the cervical spine during the slump test causes earlier activation of biceps femoris and semitendinosus may be due to these muscles attempting to reduce any excess strain being placed on localised nerves during this test. It is likely that the dissipation of strain in the nerve during the slump test occurs to prevent excess strain within a specific nerve segment in an attempt to prevent injury or re-injury. With increasing movement and therefore strain occurring within the sciatic nerve during the slump test, particularly with cervical flexion, the nerve in isolation may not be sufficient enough to prevent injury to itself; particularly if it is already sensitive to extreme movements. Consequently, the local muscular system may activate earlier to pre-empt any increases in strain to the nerve; thereby decreasing the risk of injury.

Cervical flexion caused an earlier onset of resistance (R1) as determined by the examiner, during the slump test in this study, findings which mirror that of Herrington et al. [6] who reported cervical flexion to cause a significant reduction in knee extension range of motion, when measured to R1 in healthy individuals. Johnson & Chiarello[16] cited similar findings during the slump test in healthy males, when using ankle dorsi-flexion as the structurally differentiating manoeuvre. The latter authors however, assessed the slump test to terminal knee extension; defined as the point the participant felt most comfortable extending the knee to. Despite methodological differences between this study and previous research [6,16], the effect cervical flexion had on the onset of resistance in this study reflects that of previous research. Shacklock [1] postulates that the resistance to movement a therapist feels during a neurodynamic test, is a result of muscle contraction, which is acting in a protective manner. Whilst the therapist in this study was detecting onset of resistance, this may have corresponded to an increase in muscle contraction as opposed to muscle onset.

The findings of this study supports the vast research which has highlighted the effect structural differentiation can have on the end point measurements typically used during neurodynamics tests. Whilst the majority of research has typically focussed on one of these variables in isolation, and often in healthy individuals, this study is the first to evaluate the onset of muscle activity, pain and resistance onset during the slump test in athletes with clinically diagnosed hamstring strains. This study highlights the effect cervical flexion during the slump test has on the onset of muscle activity, pain and resistance, indicating that structural differentiation has a valuable role to play in neurodynamic testing. This study is not without its limitations, in particular the limited sample size, with an inclusion criterion of rugby unionplayers only. A larger sample size, from a variety of different sports and of differing competition levels, would have enhanced this study. The lack of radiological investigations, such as MRI or ultrasound, thereby enabling a definitive diagnosis of hamstring muscle strain, specific to a muscle, is a further limitation to this study. However, radiological imaging for suspected hamstring injuries in clinical practice in the UK, particularly in semi-professional sport, is rarely undertaken, which is reflected in the cohort of this study. Whilst the findings of this study have provided information on the effect of structural differentiation on the local muscular system, pain and resistance during the slump test in hamstring injured athletes, confirming or refuting the presence of muscle damage to the hamstrings, in addition to an independent assessment of hamstring injury prior to inclusion, would have enhanced this study.

Acknowledgements

The authors affirm that we have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript.

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