Title: Time-varying surface electromyography topography as a prognostic tool for chronic low back pain rehabilitation

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Abstract

BACKGROUND CONTEXT: Non-surgical rehabilitation therapy is a commonly used strategy to treat chronic low back pain (LBP). The selection of the most appropriate therapeutic options is still a big challenge in clinical practices. Surface electromyography(EMG) topography has been proposed to be an objective assessment of LBP rehabilitation. The quantitative analysis of dynamic surface EMG would provide an objective tool of prognosis for LBP rehabilitation.

PURPOSE: to evaluate the prognostic value of quantitative sEMG topographic analysis, and to verify the accuracy of the performance of proposed time-varying topographic parameters for identifying the patients who have better response towards the rehabilitation program.

STUDY DESIGN: A retrospective study of consecutive patients.

PATIENT SAMPLE: 38 patients with chronic non-specific LBP and 43 healthy subjects.

OUTCOME MEASURES: The accuracy of the time-varying quantitative sEMG topographic analysis for monitoring LBP rehabilitation progress was determined by calculating the corresponding ROC curves.

Physiologic Measure: sEMG during lumbar flexion and extension

METHODS: Patients who suffered from chronic non-specific LBP without the history of previous back surgery and any medical conditions causing acute exacerbation of LBP during the clinical test were enlisted to perform the clinical test during the 12-week physiotherapy treatment. LBP patients were classified into two groups:"responding" and "non- responding" based on the clinical assessment. The "responding" group referred to the LBP patients began to recover after the physiotherapy treatment whereas the "non- responding" group referred to some LBP patient who did not recover or got worse after the treatment. The results of the time-varying analysis in the "responding" group were compared with those in the "non-responding" group. In addition, the accuracy of the analysis was analyzed through ROC curves.

RESULTS: The time-varying analysis showed discrepancies in the root-mean-square difference (RMSD) parameters between the "responding" and "non- responding" group. The RMSD RA and RMSD RW at flexion and extension in the "responding" group were significantly lower than those in the "non- responding" group ($P<0.05$). The areas under ROC curves of RMSD RA and RMSD RW at flexion and extension were greater than 0.7 and were statistically significant.

CONCLUSIONS:

The quantitative time-varying analysis of sEMG topography shows significant difference between the healthy and LBP groups. The discrepancies in quantitative dynamic sEMG topography of LBP group from normal group, in terms of RMSD RA and RMSD RW at flexion and extension, are able to identify those LBP subjects who are responsive to conservative rehabilitation program focused on functional restoration of lumbar muscle.

Key words: chronic low back pain (LBP), rehabilitation therapy, prognosis, Surface electromyography, time-varying topography

Introduction

In the majority of persons with low back pain (LBP), a specific diagnosis cannot be made [1, 2]. Without knowledge of the underlying cause, finding an efficacious match between any individual LBP patient and an almost infinite selection of therapeutic options is highly problematic [2, 3]. Consequently, the resulting trial and error approach to matching patients and treatment perpetuates the expense and prevalence of LBP [4-7].

While the various etiologies of LBP await discovery, investigators have attempted to improve treatment efficacy by developing diagnosis-independent techniques to match LBP patients to treatments that are likely to succeed [2, 8-10]. To date, several baseline variables have been identified that predict which patients are likely to respond preferentially to a specific therapeutic intervention. For example, Childs et al.[8] formulated a clinical prediction rule based on a constellation of five variables (symptom duration, symptom location, fear–avoidance beliefs, hip rotation range of motion and lumbar mobility). In persons who were positive for 4 or more of the 5 prediction variables, the estimated probability of treatment success using spinal manipulation was estimated at 92% of those subjects [8].

Musculoskeletal dysfunction is one of the causes of LBP and surface EMG (sEMG) is widely used in clinical experiments for biomechanical and musculoskeletal analysis. sEMG has been renowned for being non-invasive and dynamic application, a gold standard for measuring muscle function [4, 11-13]. With use of surface electrodes (sEMG), this painless and easily applied technique has been used extensively to document muscle impairments [4, 12, 14]. The objective sEMG measurement of global muscle groups is potential to offer a reliable reference for physiotherapy treatment of LBP and so to play a role as diagnostic and monitoring tools. In the past few decades, many researchers have been working in quantitizing sEMG signal for LBP assessment, such as raw sEMG, median frequency, reflex latency and positions of standing, trunk flexion/extension and sitting, etc[15-19]. Increasing number of literature reports that there are significant differences in sEMG between the LBP patients and the normal people which offer potential clinical application of sEMG for diagnosis of LBP [13, 20-22].

Although sEMG is used commonly in the spine, interpretation of its results can be problematic given the spine’s multiple layers of overlapping muscles. As a result, several investigators have developed spatial arrays of sEMG electrodes to describe regional muscle activity rather than activity on a per muscle basis. From data derived in this way, the localized sEMG root mean square [23] value of an array point can be estimated by a 2-D topographic representation of muscle electrical activity using a linear cubic spline interpolation [13]. The result is a visual representation of muscle activity over a two dimensional region [13]. Our hypothesis was that topography sEMG testing may prove more valuable to assess the lumbar muscle function during dynamic flexion-extension and its potential use to predict the prognosis of functional restoration rehabilitation in a population of chronic LBP subjects. It would be helpful to classify those patients who have good respond to conservative care.

Methods

Subjects:

A total of 43 healthy subjects (mean age = 32 ± 6.5 years, 23 males and 20 females) and 38 patients with chronic non-specific LBP (mean age = 42 ± 9.7 years, 28 males and 10 females) were recruited based on inclusion and exclusion criteria (Table 1). Approval for the study was received in advance of testing by the Institutional Review Board for clinical research ethics review. A written consent was collected from each participant.

Surface EMG Test:

All subjects received lumbar muscle sEMG test after enrolment. The sEMG data were collected from the lumbar region using a 7x3 array of electrodes applied evenly in the lumbar region from the spinal level of L2 to L5 (Figure 1). Each sEMG electrode was 1.5 cm in diameter and applied to alcohol-cleaned skin having impedance of less than 10 kΩ as measured by a multimeter (UT611, Uni-T LTD , Shenzhen, China). sEMG signals were amplified by 2000 times and filtered between 15-950 Hz. The data were acquired at a sampling rate of 2000 Hz by a data acquisition card (DAQ6063, National Instruments Inc., Austin, Texas, USA). Then, subjects were asked to perform a trunk-bending motion which has been suggested as one of the useful dynamic tasks for evaluating lumbar muscle function[13].

The trunk-bending motion consisted of three phases: flexion, relaxation and extension. Subjects were asked to bend their trunk forward for 1 second with the range of the flexion angle between 20-30 degrees as estimated by utilizing a protractor. Subsequently, they held their flexed posture for 2 seconds and then returned to the original straight standing posture for 2 second. The whole sEMG measurement was carried out under a constant room temperature so that the effect of temperature on the active potential conduction velocity and contractility in the muscle fibers was eliminated.

Rehabilitation Program:

All enrolled LBP patients completed a 12-week in-patient rehabilitation program (5 days per week) [24]. The standard exercise therapy and mobilization technique was performed in this study. The dosage, intensity and other factors related to these activities were prescribed and re-evaluated at each session by the hospital physical therapy staff. This individualized program is based on a "functional restoration program" [25, 26] that is divided into three phases: physical conditioning (5 weeks), working conditioning (4 weeks), and work readiness (3 weeks). In the physical conditioning phase, patients received 4 hours of physiotherapy (PT) and 2 hours of occupational therapy (OT) each day. These therapies focused on spinal mobilization, back muscle strengthening, cardiovascular and work skill training. In the work conditioning phase (PT: 3 hours/day, OT: 3 hours/day) and work readiness phases (PT: 2

hours/day, OT: 4 hours/day), patients continued with work simulated tasks as well as strengthening exercises, treadmill activities and pelvic stabilization training.

Clinical assessments:

At enrollment, LBP patients were asked to complete a standard intake questionnaire to obtain self-reports of age, gender, weight, height, medical history, the location and nature of their symptoms. Before and after a 12 week rehabilitation program (see below), subjects completed 1) an 11-point visual analog pain-rating scale (VAS) ranging from 0 (no pain in the last 24 hours) to 10 (worst imaginable pain in the last 24 hours)) and the 2) Oswestry Disability Questionnaire (ODQ)[27].

According to the results of the ODI and VAS evaluations, the LBP patients were categorized to 2 sub-groups as either “responding” or “non-responding” based on the minimal clinically important difference (MCID) reported for the VAS (2 points decrease)[28] or the ODQ (10 points improvement) [29]. In the present study, LBP patients exceeding the MCID of the VAS, ODQ or both were considered to be responders. Otherwise, they are regarded as “non-responding”.

Dynamic sEMG topography analysis

A total of 16 channels sEMG signals were recorded from array-electrode. A sliding analysis window of 0.2 s was employed to segment the sEMG signals along the lumbar flexion and extension. With a moving window interval of 0.1 s, a total of 50 blocks of sEMG signals was segmented from a whole circle of flexion-extension(flexion:10 blocks, relaxation:20 blocks, extension:20 blocks). In each block, root-mean-square [23] values of sEMG signals were calculated for each channel by the following equation:

$$X_{rms} = \sqrt{\frac{{x_1}^2 + {x_2}^2 + \cdots + {x_i}^2 + \cdots + {x_n}^2}{n}} \qquad (1)$$

where x_i is sEMG signal, and n is the sampling number within the analysis window (n=400 in this study). The RMS values of each analysis window were normalized to the maximum RMS value among all of the analysis windows of a whole flexion-extension circle. To construct a 2-D SEMG topography, the RMS values of the 16 SEMG channels within a definite time interval were calculated as per a 160 x 120 matrix, using a linear cubic spline interpolation of each scan as described in a published report [13]. During the whole flexion-extension circle, each block of sEMG signals can generate a frame of topography colour map. Therefore, a sequence of 50 topography frames (10 frames in flexion, 20 frames in relaxation, 20 frames in extension) can be created. Fig. 2 (a) demonstrated the 5 continuing frames of sEMG topography in flexion action. The topography represents the intensity of sEMG distribution by the colour gradient, in which a blue colour means the lowest value and a red colour is the highest value. In each frame, three topographic parameters, namely relative area (RA), relative width (RW), and relative height (RH), as proposed by a previous report[13], were used to measure the features of the highest 60% RMS value region in sEMG topography as shown in Fig. 2 (b).

After measuring 3 topographic parameters in all 50 frames of whole circle, can be plot a time-varying curve. Figure 3 demonstrated a plot of a time-varying RA curve from a normal subject. Mean and standard deviation of time-varying topography parameters from forty-three healthy subjects were calculated as the normal values. To quantify the discrepancies in the variation patterns of these parameters during the flexion and extension phases between the normal and LBP patient groups, the root-mean-square difference (RMSD) of each parameters variation pattern in LBP patient with respect to the normal group was evaluated according to the following equation.

$$\mathrm{RMSD} = \sqrt{\frac{\sum_{i=0}^{i=N}(b_i - a_i)^2}{N}} \qquad (2)$$

where is a set of the mean value from normal data (reference data), is a set of the LBP patient group data (compared data), and N is the sampling number.

In this study, all the topographic parameters of the RMSD during relaxation phase was not taken into consideration since the sEMG signals in the relaxation phase was lack of lumbar myoelectric activities. Therefore, the parameters of RMSD RA, RMSD RW, RMSD RH in both flexion and extension were calculated.

Statistical Analysis:

All presented data were analyzed using SPSS 16.0 software. RMSD RA, RMSD RW, RMSD RH in both flexion and extension from normal group and the “responding” and “non-responding” groups were compared by one-way ANOVA. The sensitivity and specificity of parameters were determined by the ROC curve. P-value < 0.05 was considered as statistically significant.

Results

Time-varying topography of healthy subjects

Figure 3 presented a sample time-varying relative area (RA) curve of a healthy subject. Time-varying curves of topography parameters, i.e. RA, RW and RH, were calculated in all healthy subjects. Then, normal patterns of time-varying RA, RW and RH can be obtained and presented in Figure 4.

Comparisons between the "responding" and "non- responding" groups

As shown in figure 4, a sample curve from a LBP patient was plotted on the normal pattern. It showed an obvious bias between LBP and normal curves. An ANOVA group comparison of time-varying RA, RW and RH showed significant difference ($p<0.05$) between the healthy and LBP groups. To each LBP patient, RMSD parameter can be calculated as a quantitative measure of the discrepancies in comparison to healthy normal data.

In this study, 16 LBP was classified as "responding" group and 23 patients as "non-responding" group. All RMSD parameters of "responding" group were consistently lower than the "non-responding" group as shown in Fig. 5. The lower the RMSD parameter value was, the closer to the normal condition, and hence the better respond to the physiotherapy treatment. Significant differences were found in RMSD RA and RMSD RW in both flexion and extension phase between the “responding” and “non- responding” groups ($p<0.05$). However, RMSD RH did not show significant difference between the “responding” and “non- responding” groups.

Accuracy test

ROC curves of RMSD RA and RMSD RW at flexion and extension were plotted out for testing the accuracy of discriminating the responding cases from non-responding cases by the RMSD parameters as shown in Fig. 6. The area under the ROC curve (AUC) of RMSD RW at extension (0.723) was the largest and followed by RMSD RA at extension (0.699). They were also found significantly different ($p=0.023$, $p=0.043$). All four RMSD RA and RMSD RW at flexion and extension had AUC larger than 0.5.

Discussion

There are various therapeutic interventions to be recommended for the treatment of LBP[9], in which exercise therapy is a commonly used management of chronic LBP[2]. The goal of this study is to evaluate the prognostic value of dynamic sEMG topography in chronic LBP patients to take an intensive non-surgical rehabilitation programme. The results support our hypothesis that topography sEMG testing is able to predict the prognosis of functional restoration rehabilitation.

While exercise rehabilitation can be considered to have better efficacy that most other interventions [10, 30], it would be unrealistic to expect a single therapeutic intervention to be capable of resolving all LBP complaints in all subjects. In various manipulative and exercise therapy[10], this study attempted to evaluate the prognostic value of dynamic sEMG topography in an intervention focused on treating excessive muscle activity. In this study, 16 of 38 LBP patients experienced pain relief or functional improvement after 12 weeks of intensive. Therefore, by understanding which subjects may respond to care in advance of its provision, the potential exists to prescribe the intervention only to those most likely to benefit[31] and thereby reduce the direct and indirect costs associated with treatment [32].

A previous report proposed the quantitative analysis of sEMG topography as an objective method for LBP rehabilitation assessment [13]. The present study further developed the time-varying quantitative analysis of sEMG topography rather than a static topography in each sub-action of the forward bending motion. Findings in time-varying parameters of sEMG topography showed significant difference in LBP ($p<0.05$), which support the previous results that LBP showed different topography from healthy subjects [13]. In addition, the aim of this study is to observe whether the time-varying sEMG topographic parameters can differentiate the “responding” group and the “non- responding” group of LBP, so as to evaluate its prognostic value.

To measure the dynamic surface EMG topography, time-varying RA, RW and RH patterns could reflect the dynamic change of lumbar muscular contraction patterns during the flexion-extension motion. In the present study, RMSD was proposed to evaluate the discrepancy of time-varying sEMG topography between any individual LBP and the mean value of healthy group. The lower of RMSD indicate the most similar pattern of the sEMG topography. As shown in figure 5, RMSD RA and RMSD RW of responding group were found to be significantly lower than that of non-responding group. Even without statistical significance, RMSD RH also showed an obvious lower value in the responding group than in the non-responding group. It suggests that the LBP patient, with the dynamic sEMG topography pattern close to normal healthy, would most likely respond to rehabilitation therapy.

Prognosis of LBP has been discussed in a lot of literatures [31, 33-39], but most of the prognostic variables are not specific with individual patient. In this study, the discrepancy of every individual patient from normal data can be quantitatively measured and plotted as figure 4. The merit of this prognosis tool is that it can provide a valuable prediction to clinician and the patient to select the most appropriate treatment on the early stage. ROC analysis On the other hand, the results of ROC curves showed that the area under curves (AUC) of four RMSD parameters, RMSD RA and RMSD RW at both flexion and extension are greater than 0.5，which prove the prognostic value of RMSD parameters.

There were two limitations in this study. The healthy subjects in the control group were younger than patients because of the difficulty to recruit healthy subjects older than 45 years old. The second limitation was that we did not collect body mass index (BMI), so as to not analyze the effect of BMI on the surface EMG topography. Four prognostic parameters of time-varying surface topography were proposed, but it is still to determine a clear threshold as well as a optimal combination of parameters for predicting prognosis in a separate study of large scale LBP population.

In summary, the quantitative analysis of time-varying sEMG topography showed significant difference between healthy and LBP groups. The discrepancies in quantitative dynamic sEMG topography from normal healthy curves, in terms of RMSD RA and RMSD RW at flexion and extension, was able to identify those LBP subjects who would respond to a conservative care program focused on functional restoration of lumbar muscle. The use of quantitative analysis of time-varying sEMG topography would help to select the most appropriate conservative treatment for chronic LBP patients.

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Legends:

Figure 1 Placement of the 3×7 electrode-array on lumbar surface

Fig. 2 A sample sequence (5 frames) of dynamic topography during flexion phases and a measurement of relative area (RA), relative width (RW), and relative height (RH)

$$\text{Relative Area (RA)} = \frac{\text{High activity area}}{\text{Total topography area}},$$

$$\text{Relative Width (RW)} = \frac{\text{Width of high activity area}}{\text{Total topography width}},$$

$$\text{Relative Height (RH)} = \frac{\text{Height of high activity area}}{\text{Total topography height}}$$

Fig. 3 A sample time-varying relative area curve of sEMG topography from a normal subject

Fig. 4 Patterns of Time varying sEMG topography parameters: RA (a), RW(b) and RH(c) (Normal range of healthy subject in red and green regions)

Fig. 5 Comparison of RMSD parameters (RMSD RA, RW, RH at flexion and extension) between “responding” and “non-responding” groups.

Values of the six tested RMSD parameters of "responding" groups are consistently lower than those of "non-responding" groups. RMSD RA and RMSD RW flexion and extension are found significantly different between groups ($p<0.05^*$)

Fig. 6 ROC curves of RMSD RA and RMSD RW flexion and extension.

The area under curve (AUC) of each ROC curve is >0.7 and is statistically significant ($p<0.05^*$).

Table1

Table 1. Inclusion and exclusion criteria

Healthy subjects
Inclusion criteria: • Age from 18 to 60 years • Normal physical and neurological examinations **Exclusion criteria:** • With occurrence of low back pain in the past 6 months. • Previous spinal surgery • Pregnancy
Low back pain patients
Inclusion criteria: • Age 18 to 60 years • A primary symptom of low back pain, with or without referral into the lower extremity • A minimum Oswestry Disability Questionnaire (ODQ) score of 30%. **Exclusion criteria:** • The presence of "red flags" as obtained from questionnaire and/or physical exam (see below), • Signs consistent with nerve root compression (e.g. positive straight-leg increase < 45 degrees or diminished reflexes, sensation, or lower-extremity strength) • Pregnancy • Previous spinal surgery • Cancer • Unexplained weight loss • Immunosuppression • Prolonged use of steroids, Intravenous drug use, Urinary tract infection, Pain that is increased or unrelieved by rest, Fever, Significant trauma related to age (e.g., fall from a height or motor vehicle accident in a young patient, minor fall or heavy lifting in a potentially osteoporotic or older patient or a person with possible osteoporosis), Bladder or bowel incontinence, Urinary retention (with overflow incontinence). Open sores, Saddle anesthesia, Loss of anal sphincter tone, Major motor weakness in lower extremities, Fever, Vertebral tenderness, Limited spinal range of motion, other neurologic findings persisting beyond one month.

Figure1
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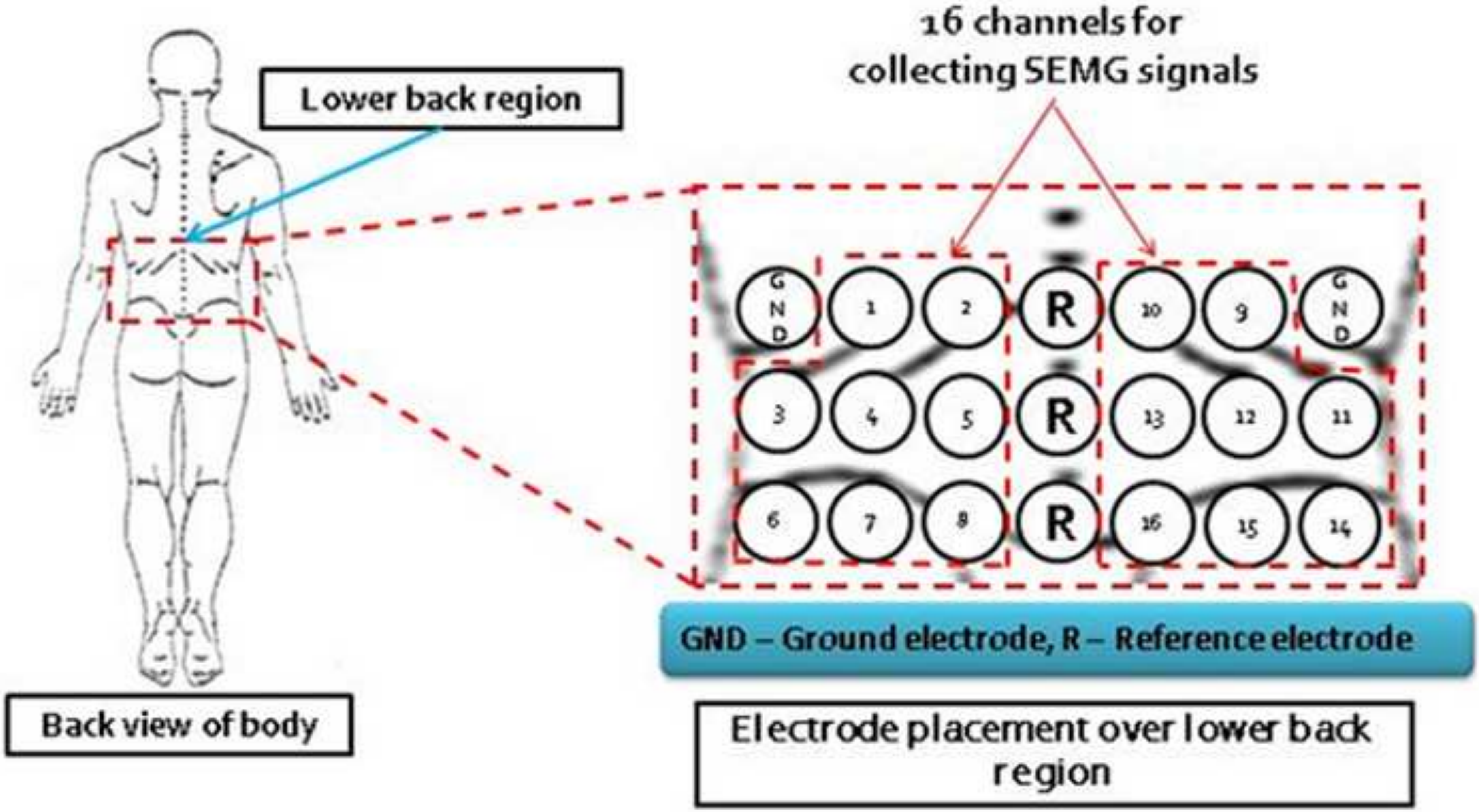

Figure2(a)
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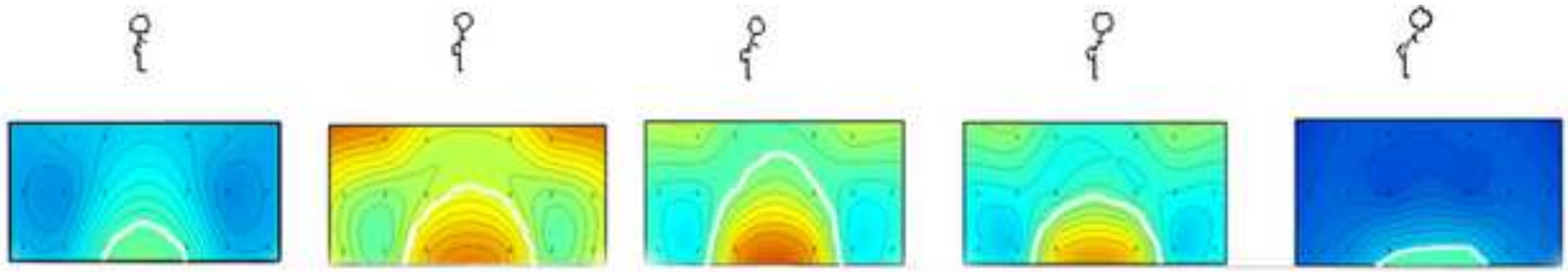

Figure2(b)
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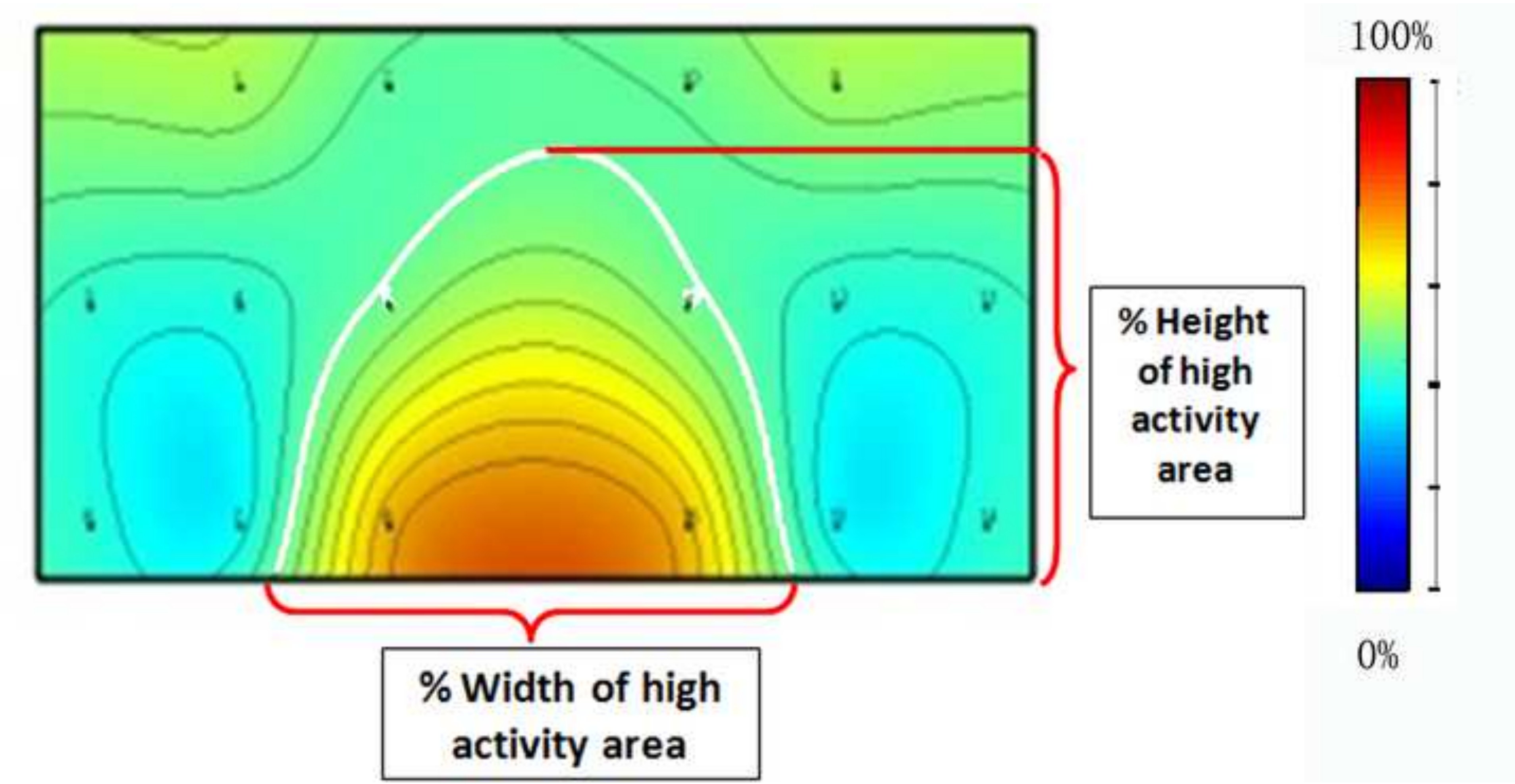

Figure4(a)
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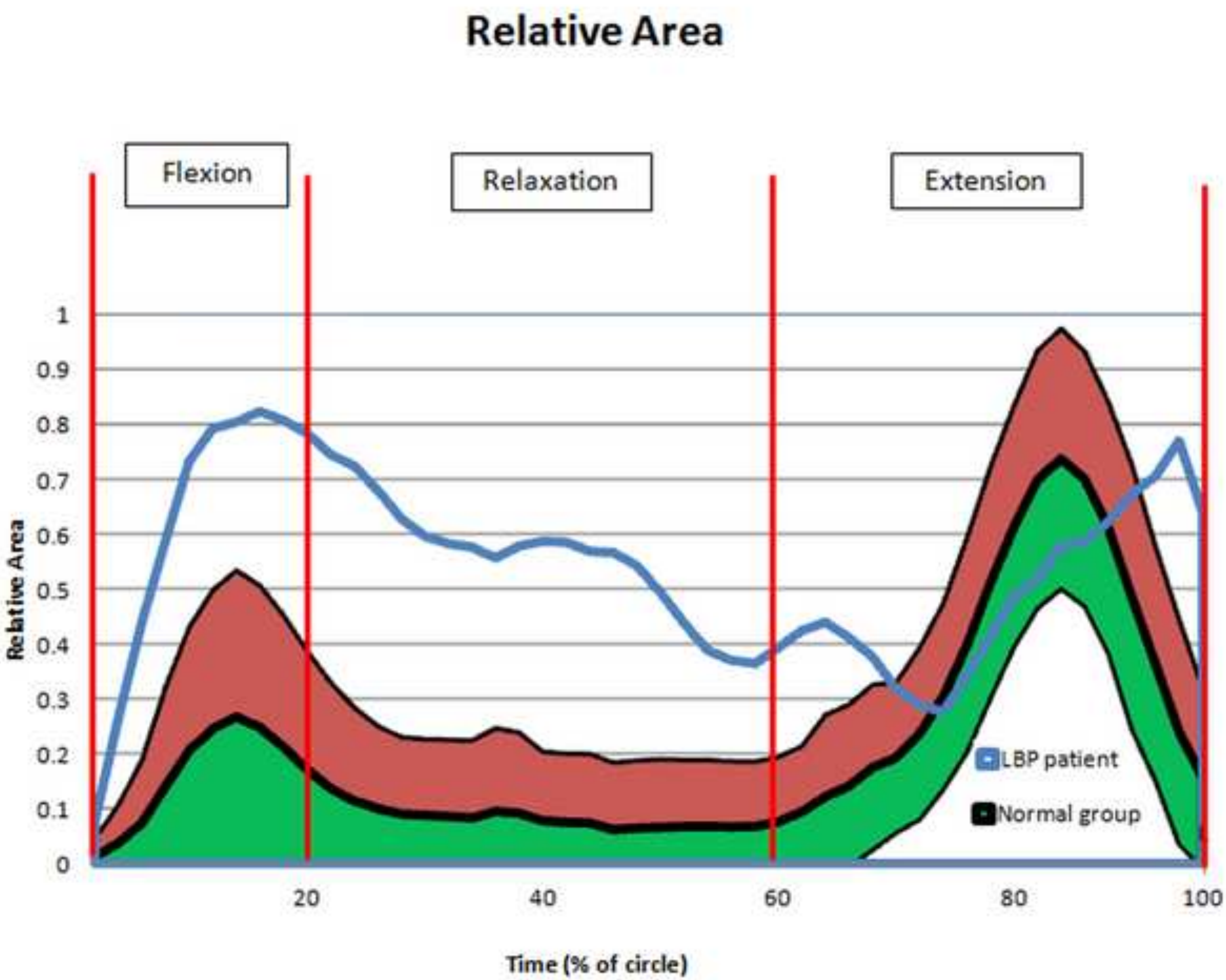

Figure4(b)
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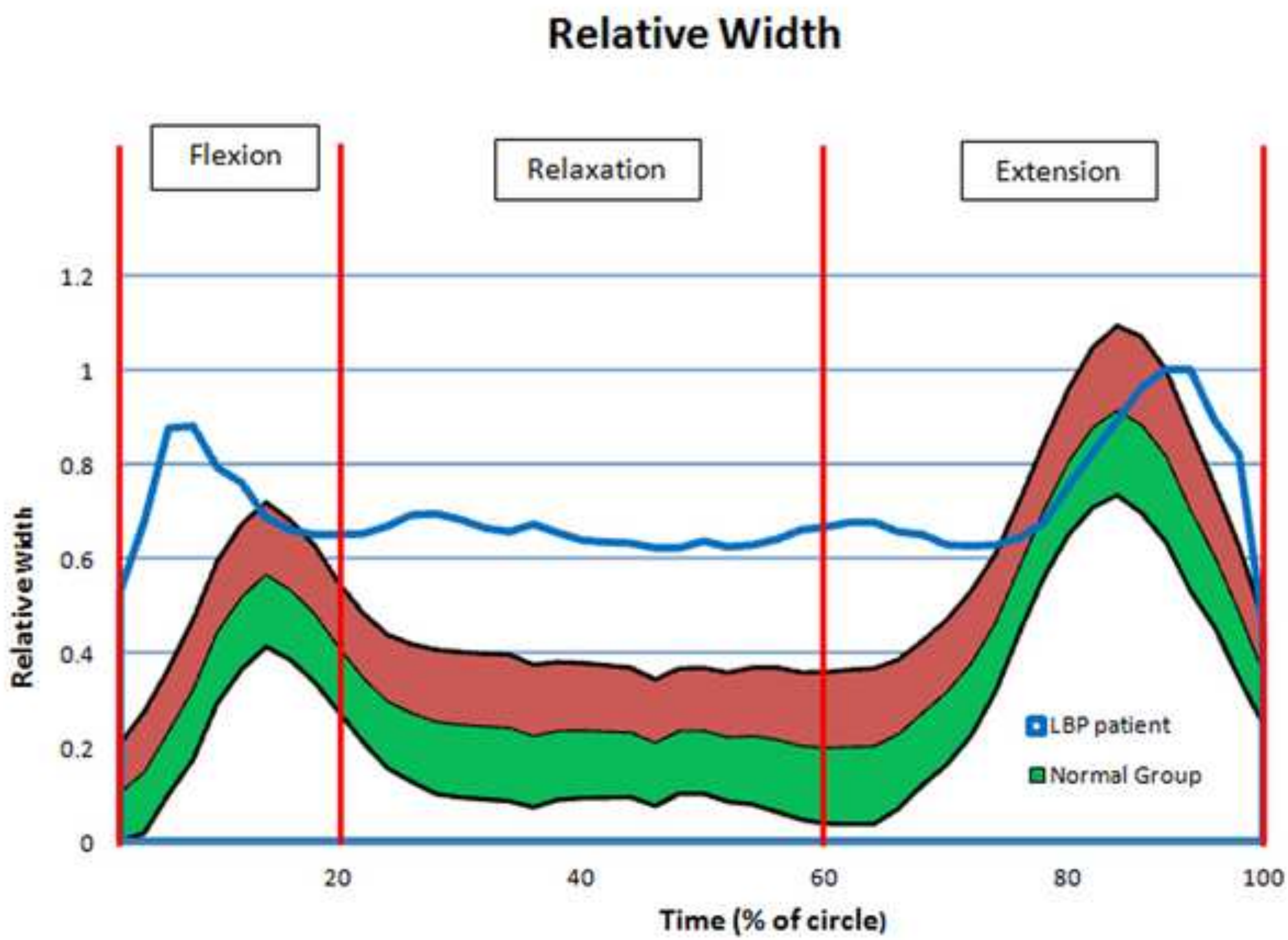

Figure4(c)
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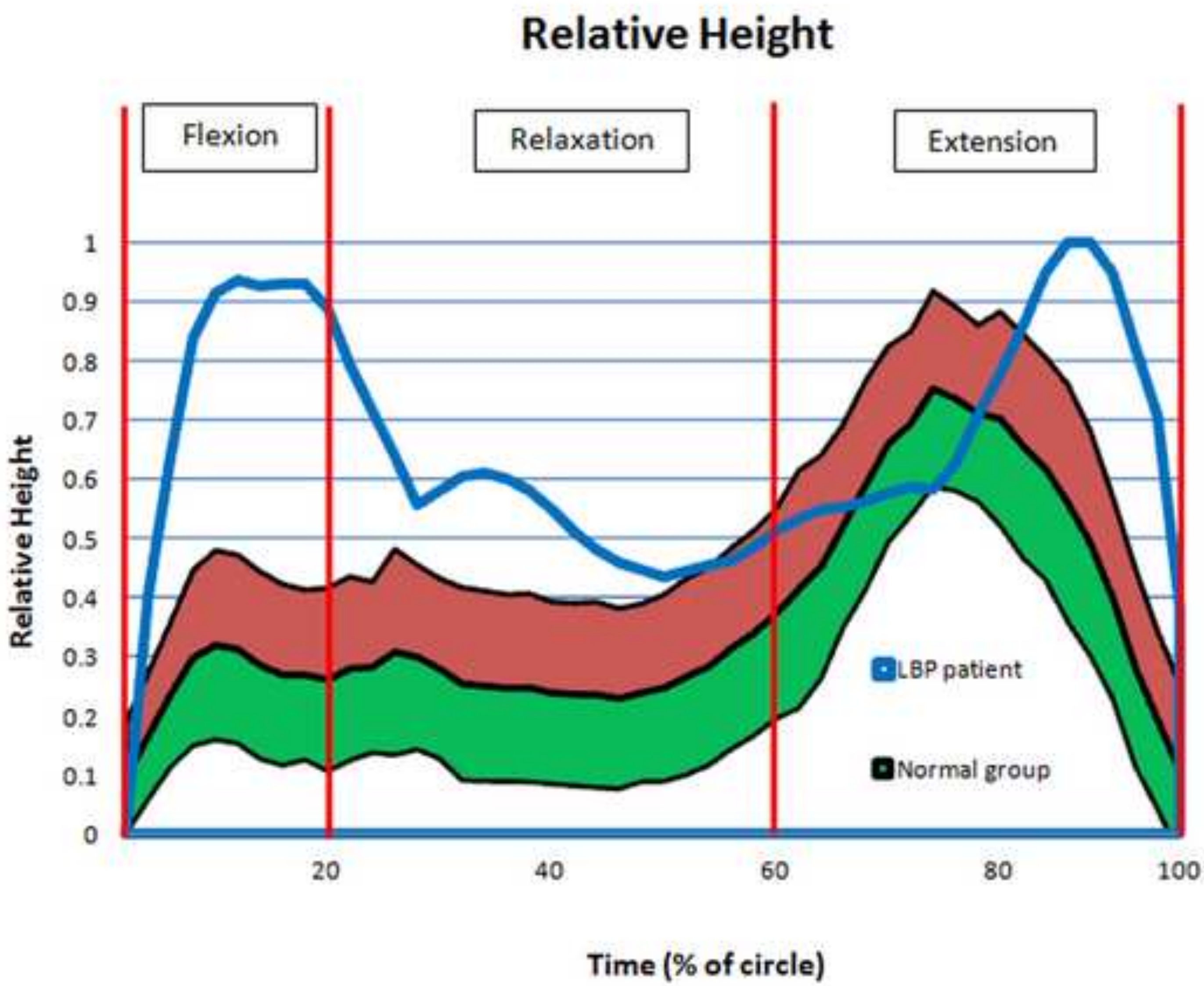

Figure5

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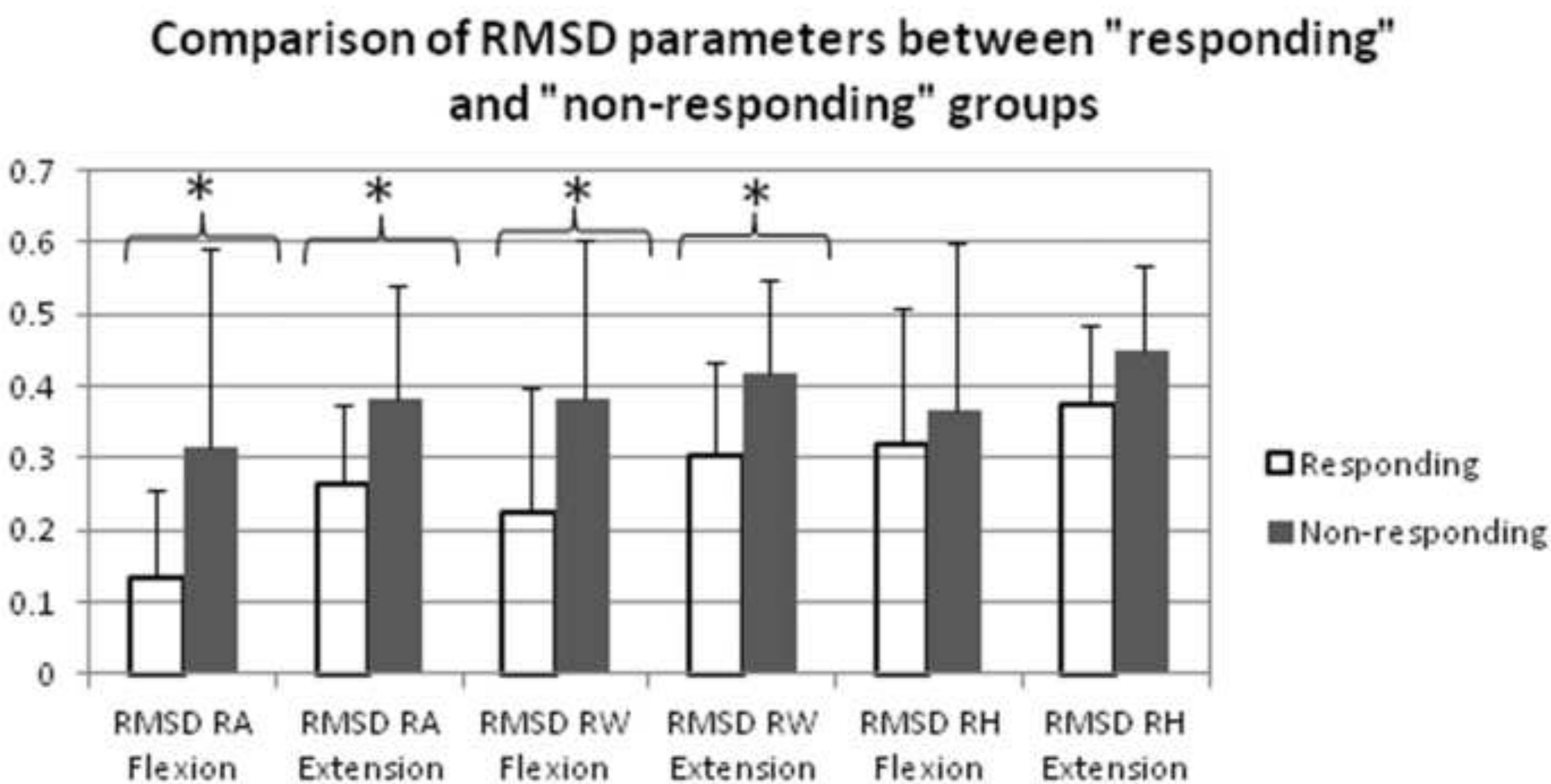

Figure6
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