METHODOLOGY OF ELECTROMYOGRAPHIC ANALYSIS OF THE TRUNK MUSCLES DURING WALKING IN HEALTHY SUBJECTS: A LITERATURE REVIEW

1 Eva Swinnen, 1Jean-Pierre Baeyens, 1Romain Meeusen and 1Eric Kerckhofs
1Vrije Universiteit Brussel, Faculty of Physical Education and Physiotherapy, Advanced rehabilitation technology and science (ARTS), Brussels, Belgium

SUMMARY
To review and discuss the literature about the use of trunk muscle electromyography - including the use of surface or fine-wire electrodes, site of application and muscle selection - during gait analysis in healthy subjects. There is no consensus on the exact placement site of the electrodes. Surface electrodes were used more often than fine-wire electrodes and the descriptions of the electrode locations were mostly vague and not consistent among the different studies.

INTRODUCTION
Gait recovery is one of the most important goals for rehabilitation. For a qualitative in-depth evaluation, there is a need of biomechanical analysis. Hereby, electromyography (EMG) is a frequently used technique to evaluate the activity of the human muscles during different motor tasks. Compared to the extensive evidence that exists on EMG activity of the lower limb muscles and their spinal regulation mechanisms (central pattern generators), only a few studies have been done specifically on the activity of the trunk muscles during walking. This, despite the fact that trunk control is very important during gait, as two thirds of the body mass is situated above the waist and the relevancy of gait control and falls in patients and in the elderly [1]. Despite the international recommendations on the placement of the surface EMG electrodes on the muscle belly (SENIAM, Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) [2, 3] and studies to determine the best electrode locations [4, 5] the literature is not consistent on these recommendations, what makes it difficult to compare the results of different studies. The aim of the present paper is to review the literature regarding the EMG registration of the activity of the trunk muscles during gait analysis in healthy subjects. We will review and discuss the muscle selection, the use of surface or fine-wire electrodes and the application sites of the electrodes in order to establish a recommendation for optimal localization of the electrodes.

METHODS
A computerized search in Pubmed, Web of Knowledge and Cochrane Library was conducted for English, French, German and Dutch articles published before March 2010. Mesh-terms and Key-words were used and sorted following the PICO (Population, Intervention, Comparison, Outcome) method. Also the reference lists in the articles and narrative reviews were scanned separately for relevant publications. Included were clinical trials or case reports with healthy adult subjects without gait problems, walking (not running) independently over ground or on a treadmill while EMG measurements of at least one abdominal and/or back muscle (excluding cervical muscles) were recorded with the use of fine-wire and/or surface electrodes.

RESULTS AND DISCUSSION
In the 33 different studies that were included, a total of 491 healthy subjects were measured for trunk EMG during walking. In 6 studies the subjects walked over ground on a walkway, in 22 studies they walked on a treadmill and in 4 studies over-ground and treadmill walking were combined. In one study no specification was given about the surface (treadmill or over ground) the subjects walked on during the tests. There was a great variability in the walking velocity. In the over-ground trials subjects walked at their natural preferred speed while in the treadmill trials the subjects walked at different determined speeds between 1 and 9 kmph. Twenty-four studies (72,7%) described an exercise-period (familiarization) before measuring. There was a large variation in the protocols used in the studies.

Research question 1: Which trunk muscles have been EMG-recorded during walking over ground or on a treadmill in healthy subjects? In 18 studies (54,5%) abdominal and back muscles were recorded and in 15 studies (45,5%) only the back muscles were recorded. The following back muscles were recorded: the M. erector spinae (ES) on different spinal levels in 33 studies, the M. multifidus (MF) in 8 studies, the M. latissimus dorsi (LD) in 6 studies, the M. trapezius (TRAP) in 7 studies and the M. quadratus lumborum (QL) in 1 study. The following abdominal muscles were recorded: the M. rectus abdominus (RA) in 17 studies, the M. obliquus externus (OE) in 15 studies, the M. obliquus internus (OI) in 11 studies, the M. transverses abdominus (TA) in 2 studies and the M. iliopeosas (ILIO) in 4 studies.

Research question 2: Which trunk muscles were measured with surface electrodes or fine-wire electrodes respectively? Twenty-nine studies (87,9%) used surface EMG electrodes and one study exclusively used fine-wire EMG electrodes. Two other studies used a combination of surface and fine-wire EMG electrodes, but the two techniques were never used in combination on the same muscle.

Research question 3: What are the exact anatomical locations described in the literature for placement of the fine-wire and surface electrodes? There is no consensus...
regarding the anatomical placement site of the electrodes on the different muscles of the trunk. Table 1 presents an overview of the different reported electrode locations for EMG of the trunk muscles.

Table 1: Overview of different described locations for electrode placement. 

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<th>Location</th>
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| ES       | 1. 2 cm lateral to midline, L1 level  
          | 2. T1-T12  
          | 3. 1 cm above intervertebral and 3 cm from midline plane  
          | 4. T1-3  
          | 5. 0.5 cm lateral to L4 SP  
          | 6. 0.5 cm lateral to L3 SP  |
| MF       | 1. 5 cm lateral to midline  
          | 2. 2 cm below iliac crest  
          | 3. 1 cm posterior to PSIS |
| LD       | 1. 5 cm lateral to midline  
          | 2. 2 cm lateral to PSIS |
| RA       | 1. 3 cm lateral to umbilicus  
          | 2. 2 or 3 cm lateral to umbilicus  
          | 3. 3 cm lateral to midline, midway between xiphoid process and umbilicus  
          | 4. 1 cm lateral to midline  
          | 5. 1 cm lateral to midline  |
| OE       | 1. 3 cm lateral to umbilicus  
          | 2. 3 cm lateral to midline  
          | 3. 1 cm lateral to midline  
          | 4. 1 cm lateral to midline  
          | 5. 1 cm lateral to midline  |
| OL       | 1. 2 cm and 1 cm above  
          | 2. 1 cm and 2 cm below  
          | 3. 1 cm lateral to midline  |
| TA       | 1. 2 cm lateral to midline  
          | 2. 1 cm lateral to midline  
          | 3. 1 cm lateral to midline  |

Most of the studies focused on the EMG activity of the lower limb muscles and including one or two back or abdominal muscles, mainly the ES or the RA. In the 33 selected studies, back and/or abdominal muscles were generally measured using surface EMG and occasionally by means of fine-wire electrodes. There is no consistent conclusion in the literature about the optimal type of electrodes for measuring superficial or deeper layer muscles in different situations (for example static or dynamic tests). No studies were found that measured the trunk muscle activity with surface and fine-wire electrodes during the same walking protocol, whether or not at the same time. It was to be expected that superficial flat muscles, such as the LD, TRAP and RA, were exclusively or almost exclusively measured with fine-wire electrodes. The electrode placement is difficult for the back and abdominal muscles because of their multilayer structure and their mostly flat presence. A cadaver study and an in vivo study were done to determine on an anatomical base the best electrode location for the back muscles in order to avoid cross-talk during measurement [4, 5]. However, precise longitudinal electrode positioning seemed to be less critical in experimental setups that measure the surface EMG of the lower back muscles.

CONCLUSIONS

We conclude that 1) the most frequently measured trunk muscles during gait were the ES, RA, OE and RA, 2) surface electrodes were used more frequently than fine-wire electrodes and 3) the descriptions of the electrode locations were mostly vague and not consistent among the different studies. At the moment in the literature no consistent information is available for writing specific recommendations for optimal localization of the electrodes. There is a need for further research to make specific recommendations about the type of electrodes in combination with the optimal locations of application.

REFERENCES