QUANTIFICATION OF MUSCULAR DEMANDS IN THE ELDERLY: ELECTROMYOGRAPHY VS. JOINT MOMENTS

by

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Title: QUANTIFICATION OF MUSCULAR DEMANDS IN THE ELDERLY: ELECTROMYOGRAPHY VS. JOINT MOMENTS

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Dr. Li-Shan Chou

This study was performed to evaluate the sensitivity of using electromyography (EMG) and joint moment to quantify muscular challenges in elderly adults. Twenty elderly and young adults walked on level ground and crossed an obstacle. Resultant hip, knee, and ankle joint moments and EMG data from muscles of the dominant leg were analyzed. Older adults demonstrated significantly greater normalized EMG (N-EMG) magnitudes than young adults in most muscles. However, only hip abductor moment demonstrated significant group differences. Stepping over a higher obstacle resulted in greater N-EMG magnitudes in all muscles. Leading limb knee extensor moment was found to significantly decrease with increasing obstacle height, while N-EMGs of knee joint muscles increased. Our findings suggest that N-EMG, which can better account for co-activation of agonist and antagonist muscles, might be a more sensitive parameter than the joint moment in detecting age- and task-related differences.

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CHAPTER I

INTRODUCTION

Background

Muscle Weakness and Aging

Significant reductions in muscle mass and strength are accompanied with aging. Frontera et al. (2000) recruited nine older adults (initial mean age = 65.4 ± 4.2 yr) in a 12-yr longitudinal study and reported that isokinetic muscle strength declines with a rate ranging from 1.4 to 2.5% per year. Furthermore, compared to young adults, older people in their seventy and eighty score, on average, about 20-40% lower on tests of isometric strength (Vandervort, 2002). Age-related loss of muscle tissues is attributed to reduced numbers of type I and II fibers (Lexell, 2000; Thompson, 1994). Also, the architecture of human gluteus medius muscle has been shown to be significantly altered in elder individuals as compared to the young adults. Anatomic cross-sectional area, volume, fascicle length and pennation angle are all found to be smaller in the elderly adults than the young adults (Narici, Maganaris, Reeves, & Capodaglio, 2003). In addition, denervation of muscle fiber, caused by death of motor neurons, could be one of the reasons for muscle strength reduction in the elderly (Larsson, 1978). Muscle strength reductions due to aging were reported to be greatest in the lower extremities (Robbins, Rubenstein, Josephson, Schulman, Osterweil, & Fine, 1989). Whole muscle analysis via cadaver or radiological observations has shown that thigh and leg muscles in older adults demonstrated significant size reductions over time than those in young adults (Hakkinen et al., 1998a, b; Janssen, Heymsfiedl, Wang, & Ross, 2000; Lexell et al., 1988).

Falls in Older Adults

Falls are the leading cause of accidental death among older adults. Approximately 33% of people over 65 years of age fall at least once a year (Sattin, 1992; Tinetti, Speechley, & Ginter, 1988). Muscle strength of the lower extremities is essential for balance maintenance and mobility. Reduced muscular strength is one of the physical changes that can significantly impact an older adult's functional ability (Aniansson, Grimby, Hedberg, Rundgren, & Sperling, 1978; Buchner, & de Lateur, 1990; Larsson, Grimby, & Karlsson, 1979). A systematic review and meta-analysis study indicated that lower extremity weakness is a clinically important and statistically significant risk factor for falls in the elderly (Moreland, Richardson, Goldsmith, Clase, & BChir, 2004). It has been demonstrated that a loss in lower extremity strength is directly correlated with the ability of elderly adults to cross obstacles_(Lamoureax, Sparrow, Murphy, & Newton, 2002). Improvement in lower extremity muscle strength may increase the speed of crossing stride and increase functional independence of older adults (Lamoureax, Murphy, Sparrow, & Newton, 2003). It appears that muscle strength is important for maintaining functional gait and stepping ability. Therefore, quantification of the muscular demand during a gait task is needed for better understanding of age-related decline in muscle function and for the development of strength training programs to improve mobility.

Quantifying Muscular Demand Using Joint Moment

Many researchers have proposed different method for quantifying the muscular demand during gait. Ratios of the peak joint moments during activities of daily living

(ADLs) to the peak torques measured during maximum voluntary contraction (MVC) were used to measure the relative muscular effort (Judge et al., 1996a, b; Hortobagyi, Mizelle, Beam, & Devita, 2003). DeVita and Tibor (2000) reported that aging causes a redistribution of joint torques and powers in the lower extremities. The elderly were reported to generate greater hip extensor moments and less knee extensor and ankle plantar flexor moments than the young when walking at the same speed. Older adults require a significantly higher proportion of the measured MVC moment in the lower extremity than young subjects to perform most of the ADLs (Hortobagyi et al., 2003). However, the joint force and moment are the net result of muscular, ligamentous forces and moments, and joint reaction force. It cannot determine the functional challenges imposed on a specific muscle. Therefore, a quantitative parameter that is able to evaluate the functional challenge imposed to a specific muscle is needed to better understand the mechanism of increasing the risk of falling in the elderly associated with muscle weakness. Such a quantitative measure could also help providing information to the development of strength training intervention programs.

Quantifying Muscular Demand Using Electromyography (EMG)

Dynamic EMG is able to provide us information about the timing and relative activation of a muscle. Several EMG studies have been performed to investigate the muscular activation pattern during locomotion (Dubo et al, 1976, Shiavi, Bugle, Limbird, 1985, 1987; Whootten, Kadaba, & Cochran, 1987, 1990a, 1990b). These normal EMG profiles help us understanding the functional role of each muscle during a gait cycle and provide insights of the baseline information for identifying abnormalities. The ratio between the EMG amplitudes collected during activities and during the MVC (N-EMG) has been used to demonstrate the muscular challenge of the individual muscle group. Older adults showed greater relative EMG activation levels when compared to young adults during walking and obstacle crossing (Hahn, Lee, & Chou, 2005).

Obstructed Gait

Crossing over an obstacle during walking is a common task that people encounter during daily living. Tripping over obstacles often causes physical injuries in the elderly

(Sattin, 1992; Tinetti, Speechley, & Ginter, 1988). It has been reported that older adults adopt a more conservative strategy, such as slower crossing speed, shorter step length (Chen, Aston-Miller, Alexander, & Schultz, 1991), and reduced anterior-posterior center of mass and center of pressure separation (Hahn & Chou, 2004), while negotiating with an obstacle during gait. It was also reported that stepping over a higher obstacle results in greater internal hip abduction, knee extension, and ankle plantar flexion moments of the trailing limb (Chou & Draganich, 1997, 1998; Kovacs, 2005). Furthermore, greater relative activations in the gluteus medius, vastus lateralis, and gastrocnemius were found when crossing over a higher obstacle (Hahn, Lee, & Chou, 2004). Lee (2005) applied both the joint moment normalized to the peak joint moment measured during the maximum isometric voluntary contraction (N-moment) and the normalized EMG ratios (N-EMG) to quantify muscular challenges during unobstructed and obstructed walking, and demonstrated that these ratios could demonstrate a similar ability in detecting functional challenge applied onto lower extremity muscles. In this study, the leading limb peak knee extensor N-moment ratio, especially elderly adults, was found to decrease when crossing a higher obstacle, which was opposite to the trend illustrated by the vastus lateralis N-EMG ratio. As mentioned previously, the normalized moment data is a resultant moment of all muscular efforts surrounding the joint, including both agonist and antagonist muscles. If a co-activation exists, the resultant moment about the joint can be small due to the counter-balancing effect. It has been reported that co-activation of the antagonist is necessary to assist the ligaments in maintaining joint stability, and regulating the mechanical impedance on a joint (Baratta et al. 1988). In other words, even though the N-moment is small, it does not necessarily mean that the muscle activation is also small. Lee indicated that, when strong co-activation of agonist and antagonist muscles is present, using the N-Moment ratio could underestimate the muscular challenge. However, only activations from agonist muscles were recorded in his study. Information about the antagonist muscle activities was lacking.

Purpose and Hypotheses of the Study

In this study, we sought to provide such evidence by recording activations of both agonist and antagonist muscles around selected joints to confirm this co-contraction phenomenon. Also, we would assess the ability of using these two ratios (N-moment and N-EMG) to quantify muscular challenges in young and elderly adults and with different task difficulties.

The first hypothesis of this study was that both the N-EMG and N-moment would demonstrate similar trends in the quantification of muscular challenge during different gait tasks. Second, we expected that the elderly adults would demonstrate higher N-EMG and N-moment ratios than young adults. Third, when a strong co-activation between agonist and antagonist muscles is present, compared to the N-moment ratio, N-EMG ratio would provide a better quantification of muscular challenges.

CHAPTER II

METHODS

Subjects

Ten healthy older adults (mean age = 70.7 ± 3.3 years, height = 172.7 ± 8.6 cm, weight = 76.8 ± 15.2 kg) and ten young healthy adults (mean age = 21.9 ± 2.0 years, height = 174.4 ± 10.1 cm, weight = 71.1 ± 17.1 kg) were recruited in this study. Subjects were recruited by posting fliers on the University of Oregon campus, and the YMCA in Eugene. All subjects were asked to sign the informed consent form (Appendix A) approved by the institutional review board of the University of Oregon prior to testing.

Inclusion criteria of this study required that subjects have no histories of neurological disorders (e.g. stroke, Parkinson's disease, and traumatic brain injury), vestibular problems, uncorrectable visual impairments, or severe muscular skeletal impairments that can interfere with steady gait. All subjects scored 56 (Full points = 56) in Berg balance scale (Berg, Wood-Dauphinee, William, & Maki, 1992) (Appendix B), which was used to measure the balance ability of all subjects. In addition, the mental status all subjects were assessed using the Folstein Mini-Mental test as suggested by a score of 28 or higher (>28/30) (Folstein, Folstein, & McHugh, 1975) (Appendix C).

Experimental Instruments

Isokinetic Dynamometer System

Isometric maximal voluntary contraction (MVC) tests were performed by Kinetic Communication Exercise System (Kin-Com, Chattecx, TN).

Electromyography System

A six-channel electromyography (EMG) system (MA 300-6, Motion Lab Systems, Inc., Louisiana), which detecting full-bandwidth EMG activities from 20Hz to 2000Hz, was used in this study. A desktop interface unit and a subject back-pack were the main components for the EMG system. A single thin, superflexible, 3/32" diameter coaxial cable connects and transfers information from the subject back-pack to a desktop receiver.

Six active surface EMG electrodes (pre-amplifiers) (MA-311, Motion Lab System, Inc., Louisiana) were used during the experiment. The input impedance of the amplifier was greater than 100,000 M and the Common Mode Rejection Ratio (CMRR) was greater than 100dB at 65 Hz. The system gain was 20 dB at 200 Hz.

Force Plates

Two AMTI (Advanced Mechanical Technology, Inc., Watertown, MA) force plates were used to collect the ground reaction forces and moments with a sampling rate at 960 Hz. Both force plates were placed in the middle of the walk way.

Motion Analysis System

An eight-camera motion analysis system (Motion Analysis Corp., Santa Rosa, CA) was used to collect 3-dimensional (3-D) marker trajectories. The 3-D motion data were collected at 60Hz and low-pass filtered using a forth order Butterworth filter with a cut-off frequency of 8 Hz. The motion analysis system was calibrated prior to each subject's test.

EMG data and ground reaction force measurements were time synchronized to the video sampling rate.

Data Collection and Experimental Procedures

Muscle Strength Measurement

The dominant leg of each subject was chosen to be the testing limb. Before starting the maximal voluntary isometric muscle strength testing, the dominant leg of each subject was determined as the leg the subject uses to kick a ball.

Muscle Selection

The gluteus medius (GM), adductor Magnus (AM), vastus lateralis (VL), semitendinosus (ST), medial head of gastrocnemius (GA), and tibialis anterior (TA) muscles of the dominant leg were included in this study, and their EMG activities were monitored. The gluteus medius, vastus lateralis, medial gastrocnemius were selected based on previous findings indicating that hip abductor, knee extensor and ankle plantarflexor are challenged when stepping over a higher obstacle during gait (Chou & Draganich, 1997). Adductous magnus was selected to be the antagonist muscle of the GM, and it is the most accessible hip abductor. Also, the onset time of the AM during the gait event was reported to be more syncondronize with that of the GM (Jacquelin, 1992). Primary functions of knee flexors in gait are to lift the foot for clearance and provide shock absorption during the loading response (Dubo et al., 1976). The two medial hamstring muscles often start their activations in the late mid- and terminal swing phase and continue throughout the mid stance to stabilize the knee joint, while the biceps femoris only continues at a lesser level into the early loading phase (Jacquelin, 1992). Therefore, the ST, which is one of the medial hamstring muscles, was chosen as the antagonist muscle of the VL because the position of the ST is more superficial than the semimembranosus.

The tibialis anterior was chosen to be the antagonist muscle of the medial GA since it has the largest cross section area among the three ankle dorsiflexors (Jacquelin, 1992), and it is a superficial muscle that allowed us to get better signal from the surface EMG electrode.

Electromyography Electrodes Placement

EMG data from the above-mentioned six muscles of the dominant leg were recorded during the maximal voluntary isometric muscle strength testing as well as gait analysis. EMG signals were sampled at a rate of 960 Hz with a band pass filtering between 20 and 350 Hz. Skin surface was cleaned before the electrode placement using alcohol pads to reduce impedance. Prior to all testing, baseline EMG data were collected immediately after the electrode placement while subject was relaxed, lying on the examination table.

The surface EMG electrode for the GM was placed at the location one inch distal to the midpoint of the iliac crest. For the AM, the electrode was placed midway between the medial femoral epicondyle and the pubic tubercle.

For the ST, the electrode was placed midway on a line between the medial epicondyle of the femur and the ischial tuberosity. The electrode for the VL was placed over the lateral aspect of the thigh, one handbreadth above the patella. For medial head of the GA, the surface electrode was placed one handbreadth below the popliteal crease on the medial mass of the calf.

For the AT, the surface electrode was placed four fingerbreadths below the tibial tuberosity and one fingerbreadth lateral to the tibial crest (Aldo, 1994). After electrode placement, subjects will be instructed to do resisted hip abduction, adduction, knee extension, flexion, ankle dorsi flexion and toe standing to confirm the correct electrode placement. Then the electrodes were taped and secured to ensure appropriate contact with skin surfaces.

Isometric Maximal Voluntary Contraction Measurement

Joint moments of the isometric maximal voluntary contraction test (MVC) for the hip abductors, hip adductors, knee extensors, knee flexors, ankle plantar flexors, and ankle dorsi flexors of the dominant leg were determined using the Kinetic Communicator Exercise System (KinCom) (Chattecx, Hixson, TN). EMG data of the six muscles were collected at the same time.

Isometric joint moment of the hip abductors and adductors were measured when the subject was in a side-lying position with trunk and hip in a neutral position in the frontal plane. The application pad of KinCom dynamometer was applied to the lateral distal end of the femur for abduction, and medial distal end of the femur for adduction. During testing, subjects were not allowed to rotate the testing limb or use any compensating strategy from the other body segments.

Isometric joint moments of the knee extensors and flexors were tested in a seated position at 60 degrees of knee flexion. For knee extension, the application pad was placed at four finger widths above bilateral malleolus of the anterior leg. For knee flexion, the application pad was placed on the posterior leg.

Isometric joint moments of the ankle plantar flexors and dorsi flexors were measured in a seated position at 20 degrees of knee flexion and neutral ankle position. Velcro straps were used to tighten the chest and anterior superior iliac spines to stabilize the trunk, and across the distal thigh to stabilize the testing limb.

The axis of KimCom dynamometer was aligned with the joint axis of rotation during each test. Before the formal testing, each subject was allowed to perform two sub-maximal practice trials. The subjects were asked to push as hard as possible against the application pad for 5 seconds or until the plateau, showing on the monitor, had been reached for 2 seconds. A one minute rest period between any two tests was provided to avoid muscle fatigue. Data from at least three trials were collected for each joint function.

To avoid motor learning effects, additional trials were only performed until there was a decrease in strength from the previous trail.

Gait Analysis

A total of 29 markers were placed on the subject's bony landmarks (Figure1). A more detailed description of the marker placement is provided in a previous study (Hahn & Chou, 2004). The experimental protocol included walking on a level surface and stepping over an obstacle corresponding 2.5% or 10% of the individual's body height. Subjects were asked to walk along the 10 m walkway with self-selected pace while barefoot. Whole body 3-D motion data were collected with an eight-camera motion analysis system (Motion Analysis Corp., Santa Rosa, CA). The order of the obstacle condition was randomly assigned. Two force plates were aligned in series to collect the ground reaction forces. The obstacle was positioned in the center of two plates. Subjects were asked to step over the obstacle and were also asked to alternate their legs for being the leading or trailing limb. At least six trials were recorded for each walking condition.

Data Analysis

All kinematics, kinetic, and EMG data during the dynamic gait trials were analyzed through the processing software EvaRT 5.0 (Motion Analysis Corp., Santa Rosa, CA).

Gait Phases during a Gait Cycle

Each gait cycle of the trailing and leading limb was divided into four phases (Figure 2). The four phases for trailing limb were defined as the following: Phase I (double stance phase), from heel strike before the obstacle of the trailing limb to toe off of the leading limb; Phase II (single stance phase), from toe off of the leading limb to heel strike of the leading limb after crossing the obstacle; Phase III (double stance phase), from heel strike of leading limb after the obstacle to toe off of the trailing limb; Phase IV (swing phase), from toe off of the trailing limb to heel strike of the trailing limb after crossing the obstacle. The four gait phases of the leading limb were defined similarly but in a different sequence: Phase I (swing phase), from toe off of the leading limb before the obstacle to heel strike of the leading limb after crossing the obstacle; Phase II (double stance phase), from heel strike of the leading limb to toe off of the trailing limb behind the obstacle; Phase III (single stance phase), from toe off of the trailing limb to heel strike of the trailing limb after crossing the obstacle; Phase IV (double stance phase), from heel strike of the trailing limb to toe off of the leading limb.

Isometric Joint Moments during Maximum Voluntary Contraction

The peak isometric MVC joint moment was obtained from each trail and the average value among three trails for each joint function was calculated. The peak isometric MVC joint moments were then normalized by the individual's body mass (Kg) and height (m).

Resultant Joint Moments during Gait

OrthoTrak software (version 6.2.4, Motion Analysis Corp., 2004) was used to calculate net joint moments of both the trailing and leading limbs during a gait cycle. The peak hip abductor, knee extensor, ankle plantar flexor moments were first normalized by body weight (Kg) and body height (m). Later, these three peak moments were then normalized by each of the peak isometric joint moments, respectively, to yield normalized joint moment ratios (N-moment). This ratio is considered to account for both the demand imposed by the activity and the muscle strength capacity of the individual. These normalized joint moment ratios were used for further analysis. A customized Matlab program (Version 7, MathWorks Inc., Natick, MA) was used to perform signal processing, and generate the final output data.

Electromyography data

Analog EMG data were first converted into ASCII files. All EMG signals were full-wave rectified and then filtered with a 4^{th} order Butterworth band-pass filter with the cutoff frequency at 10 Hz. EMG data of each muscle collected during walking and obstacle crossing trials were then calibrated by subtracting the baseline magnitude obtained from a resting trial. Calibrated EMG values were then normalized by dividing the maximum magnitude obtained from MVC trials (Figure 3). This normalized EMG ratio (N-EMG) can allow us to monitor the instantaneous percentage of usage from the selected muscle activation during a gait cycle. The mean N-EMG ratios were then calculated for each gait phase. The mean N-EMG ratios of the gait phase during which the peak N-moment occurred were selected for further analysis.

Statistical Analysis

Age effects on the peak joint moments measured during MVC trails were determined by an independent sample t-test. Two-way ANOVA with repeated measure of obstacle height was used to detect the effects of age and obstacle height on temporal-distance gait parameters, mean N-EMG values, net peak moments, and N-moments. The significant level was set at $\alpha = 0.05$ for all tests. SPSS version 14.0 (SPSS Inc., Chicago, IL) was used for all statistical analyses.

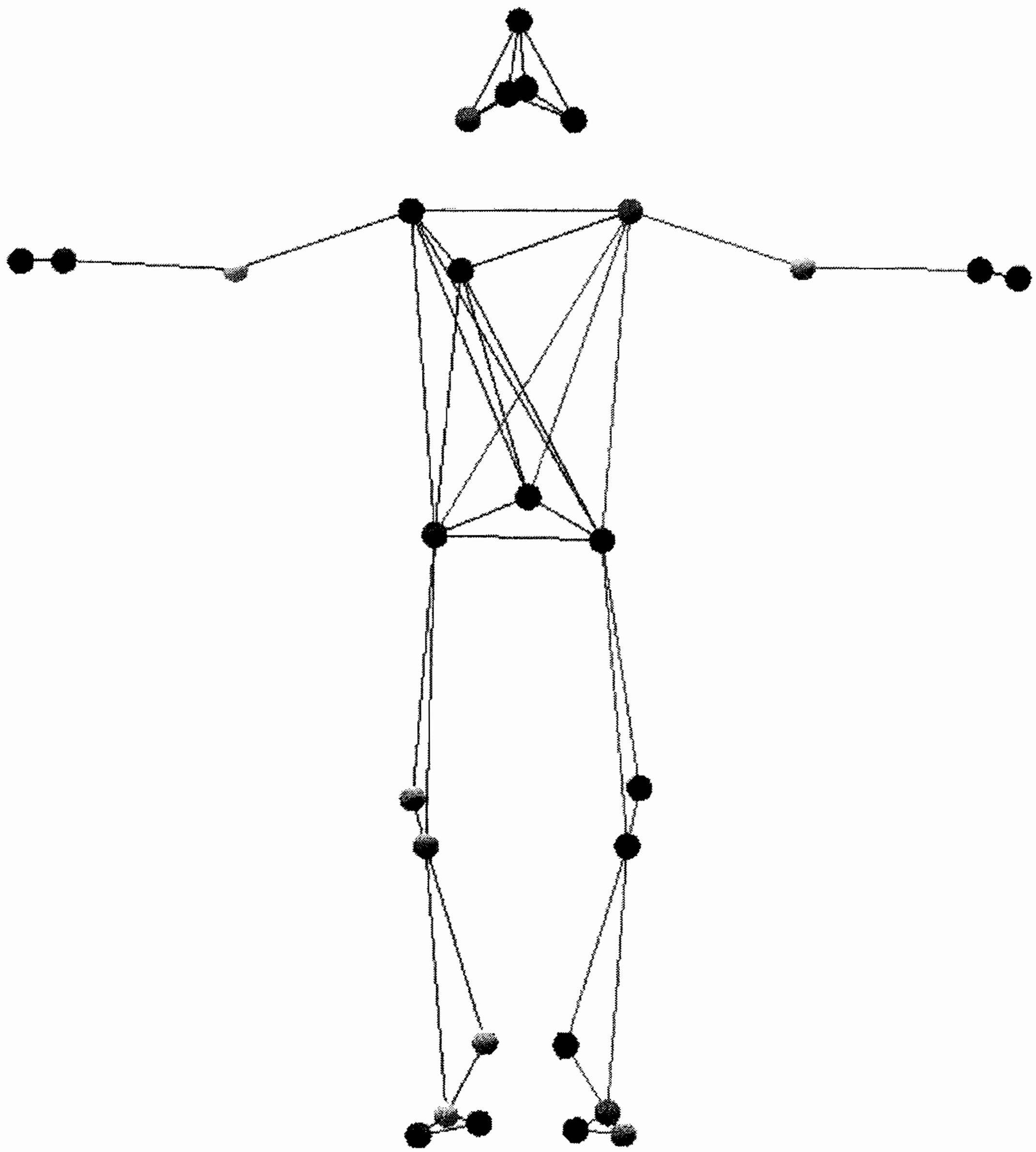


Figure 1. 29 marker set for the dynamic trial

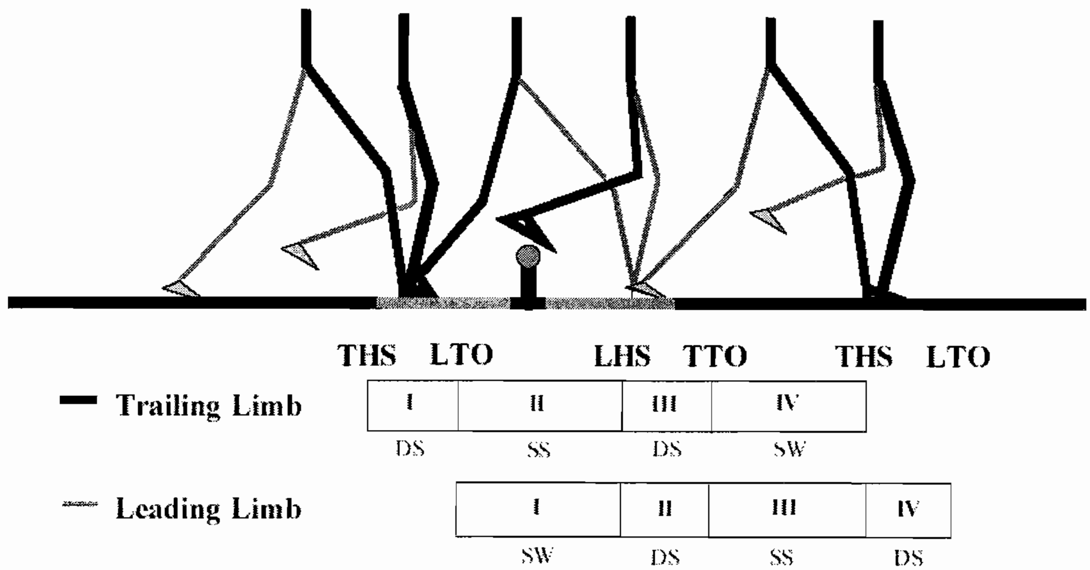
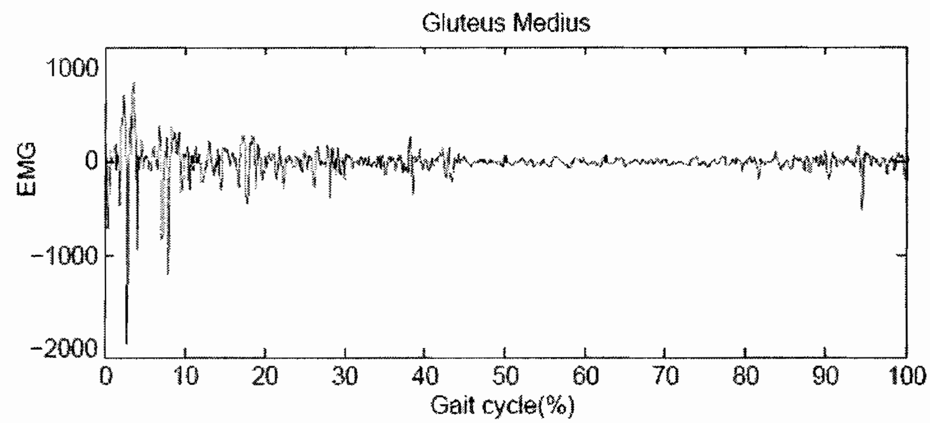


Figure 2. Gait phases during a gait cycle of the trailing and leading limb. THS: heel-strike of the trailing limb, LTO: toe-off of the leading limb, TTO: toe-off of the trailing limb, DS: double support, SS: single support, SW: swing phase.

(a)



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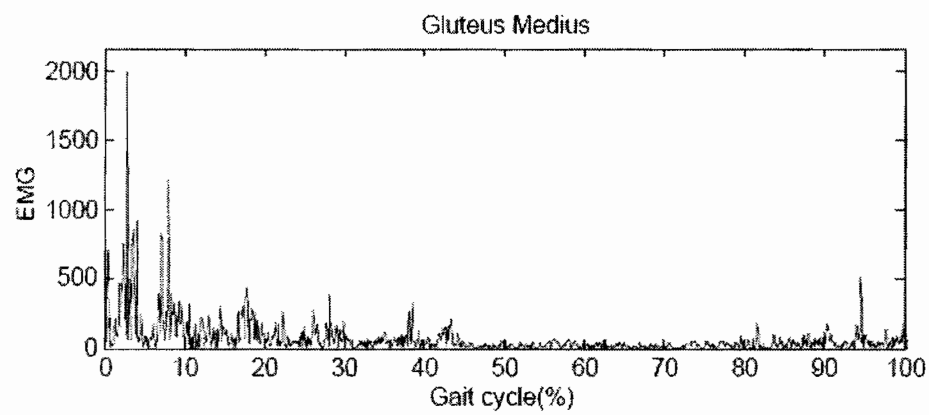

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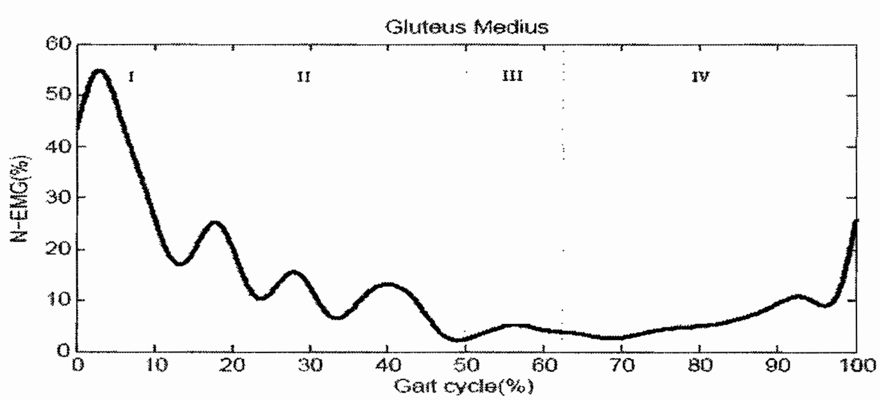


Figure 3. Representative (a) raw EMG activation of the GM, (b) rectified GM activation, and (c) smoothed GM activation (after normalization to the maximum isometric contraction) during a gait cycle (%) of level walking.

Phase I: THS-LTO; Phase II: LTO-LHS; Phase III: LHS-TTO; Phase IV: TTO-THS

CHAPTER III

RESULTS

Temporal-distance Gait Measurements

Neither discomfort nor fatigue was reported from any of the subjects during the testing. In addition, no tripping was observed during any of the obstacle crossing trials. No significant age group differences were found for any of the temporal-distance parameters (Table 1). Gait velocity was found to significantly decrease with increased obstacle height ($p < .001$). However, No significant obstacle height effect was detected for stride length and step width.

Isometric Joint Moments during Maximum Voluntary Contraction

Mean values and standard deviations of isometric joint moment during MVC were normalized by individual's body mass times body height (Table 2). Young adults demonstrated significantly greater maximum isometric joint moments than elderly adults in the hip abductor and knee extensors ($p = .046$, and $p = .025$, respectively). However, significant differences between the young and older adults were not detected in the normalized isometric joint moments of the ankle plantar flexors ($p = .403$).

Joint Moments during Gait

Patterns of the resultant joint moments of the hip abductor/adductor, knee flexor/extensor, and ankle dorsi-plantar flexor during level walking of a young subject were shown in Figures 4, 5, and 6. Similar patterns were found for the obstacle crossing conditions. The resultant hip abductor moment showed two peaks during the gait cycle. The first peak of the net hip abductor moment and peak resultant knee extensor moment of the trailing limb and leading limb were found at the beginning of phase 2 and phase 3, respectively. The peak resultant ankle plantar flexor moments of both limbs were found mostly in early double stance phase (phase 3 and phase 4 for trailing and leading limb, respectively).

Table 1. Gait temporal-distance measurements for all groups: group means (S.D.)

Subjects	Unobstructed		2.5% Obstacle		10% Obstacle		p-values
	Young	Elderly	Young	Elderly	Young	Elderly	
Gait velocity (m/s)	136.94 (15.46)	138.22 (15.10)	130.14 (17.61)	128.85 (20.32)	120.42 (15.33)	117.61 (19.96)	$p_h < .001$* $p_g = .860$
Stride length (cm)	143.36 (16.10)	140.41 (16.03)	143.11 (19.33)	138.01 (18.89)	143.49 (15.78)	136.33 (19.44)	$p_h = .324$ $p_g = .358$
Step width (cm)	10.62 (2.59)	11.09 (2.85)	10.90 (2.24)	11.12 (2.73)	11.76 (2.01)	11.35 (2.90)	$p_h = .229$ $p_g = .364$

* p_h represents height effect; p_g represents group effect.

Table 2. Normalized isometric joint moments measured during MVC: group means (S.D.)

Subjects	Healthy young	Healthy elderly	p-values
Hip Abductors (Nm/Kg*m)	0.57 (0.05)	0.47 (0.13)	$p = .046$
Knee Extensors (Nm/Kg*m)	0.83 (0.23)	0.60 (0.20)	$p = .025$
Ankle Plantar Flexors(Nm/Kg*m)	0.48 (0.10)	0.43 (0.18)	$p = .403$

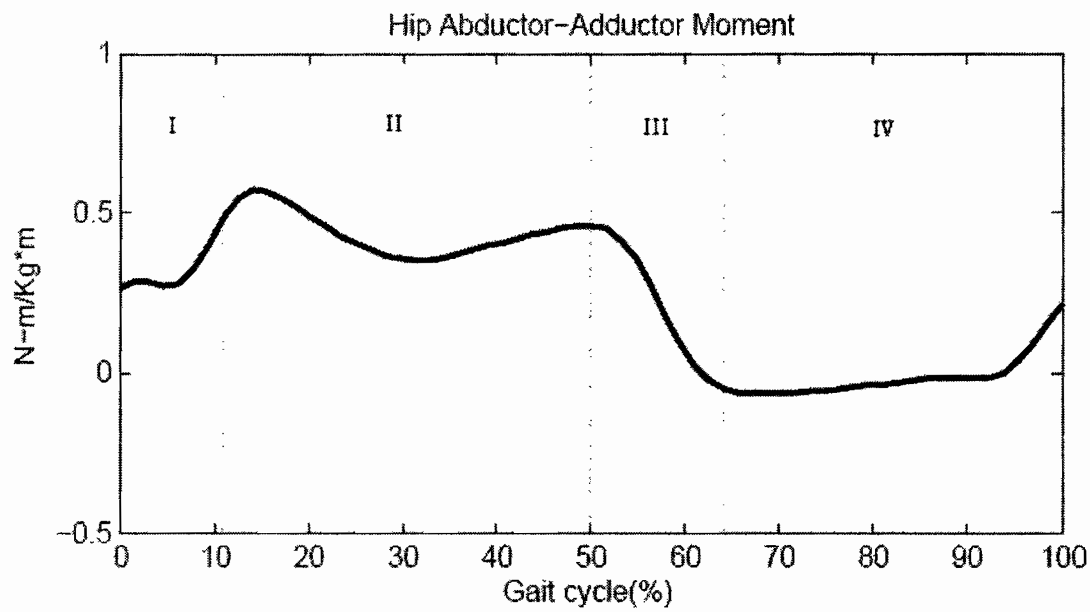


Figure 4. Resultant hip abd-add moments of the trailing limb during an unobstructed gait cycle. (+: indicate abductor moments)

Phase I: THS-LTO; Phase II: LTO-LHS; Phase III: LHS-TTO; Phase IV: TTO-THS

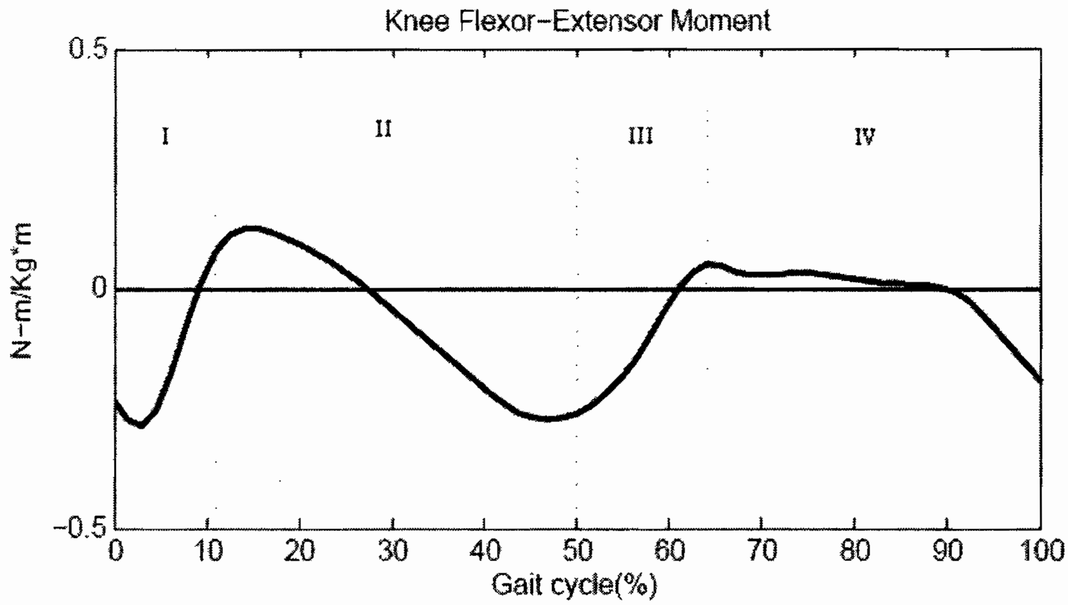


Figure 5. Resultant knee flexor-extensor moments of the trailing limb during an unobstructed gait cycle. (+: indicate extensor moments)

Phase I: THS-LTO; Phase II: LTO-LHS; Phase III: LHS-TTO; Phase IV: TTO-THS

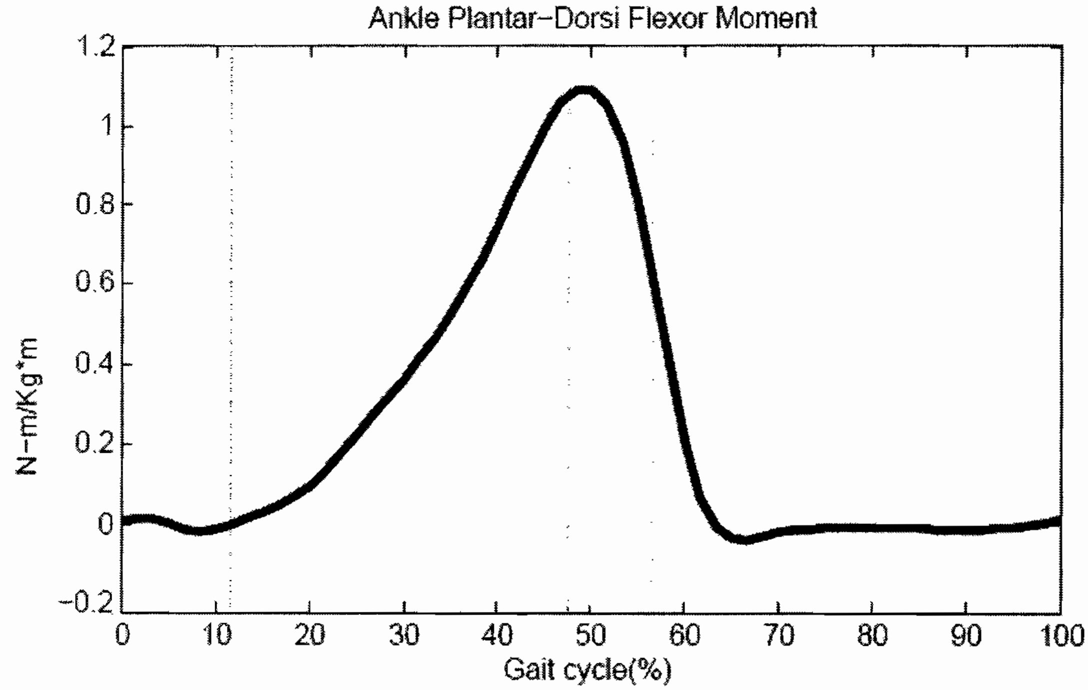


Figure 6. Resultant ankle plantar-dorsi flexor moments of the trailing limb during an unobstructed gait cycle. (+: indicate plantar flexor moments)

Phase I: THS-LTO; Phase II: LTO-LHS; Phase III: LHS-TTO; Phase IV: TTO-THS

Net Joint Moments during Unobstructed and Obstructed Gait

Significant age group effects were detected in the hip abductor peak joint moment for both limbs (Figures 7, 10). Elderly adults demonstrated a significant greater peak hip abductor moments than healthy young adults in both leading and trailing limbs.

The peak hip abductor moments of both limbs as well as peak ankle plantar flexor moments of the trailing limb were found to significantly increase when stepping over a higher obstacle (Figure 7, 10, 12). No significant group or obstacle height effects were found for the peak ankle plantar flexor moments of the leading limb and the peak knee extensor moments of the trailing limb (Figure 11). The leading limb knee extensor moment significantly decreased with the increasing obstacle height from 2.5%BH to 10%BH (Figure 8).

N-moment Ratios during Unobstructed and Obstructed Gait

Elderly adults demonstrated a trend of having greater N-moment ratios of all joints than healthy young adults in both leading and trailing limbs (Figures 13-18). However, only the hip abductor N-moment ratios reached statistically significance (Figures 13, 16). Significant obstacle height effects were found only in the hip abductor N-moment ratios of both trailing and leading limbs (Figure 13, 16).

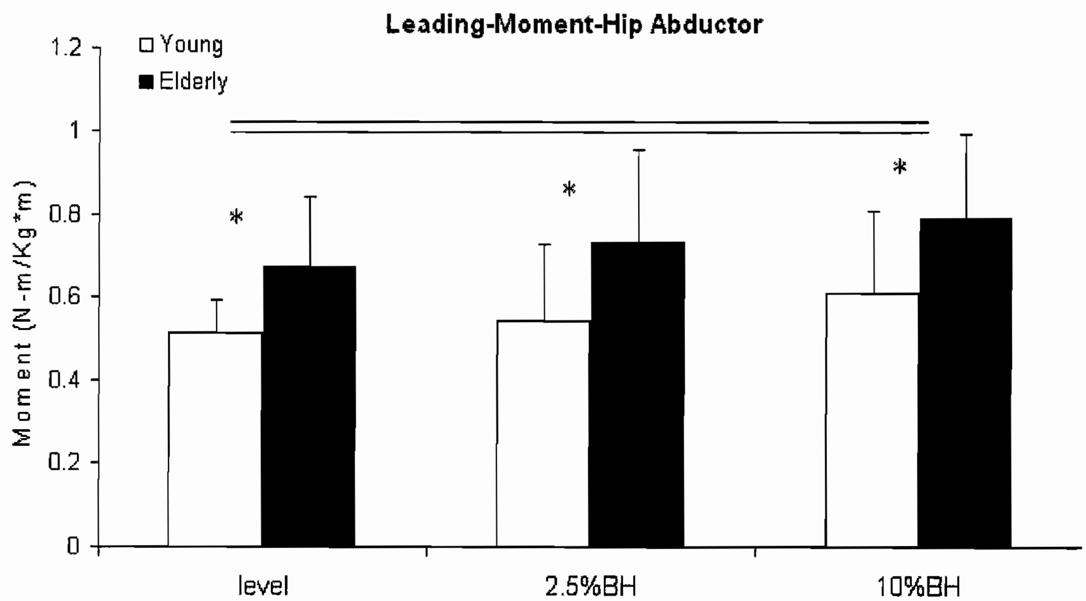


Figure 7. Peak hip abductor moment (normalized by the body height and weight) of the leading limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p = 0.014$). Asterisks denote significant differences with age ($*p < 0.05$).

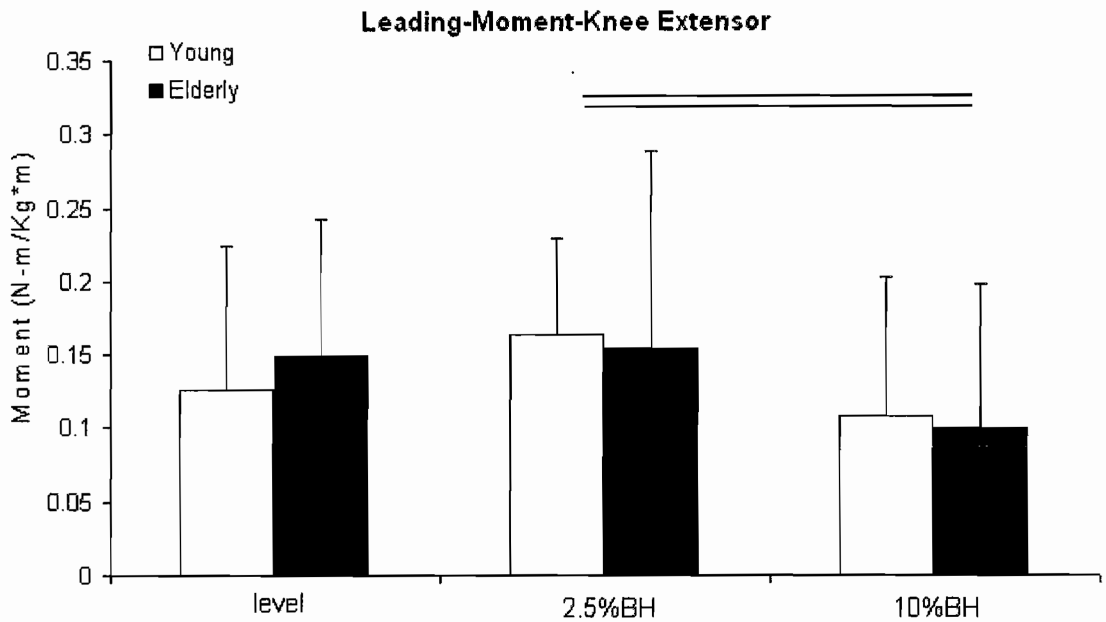


Figure 8. Peak knee extensor moment (normalized by the body height and weight) of the leading limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p = 0.019$).

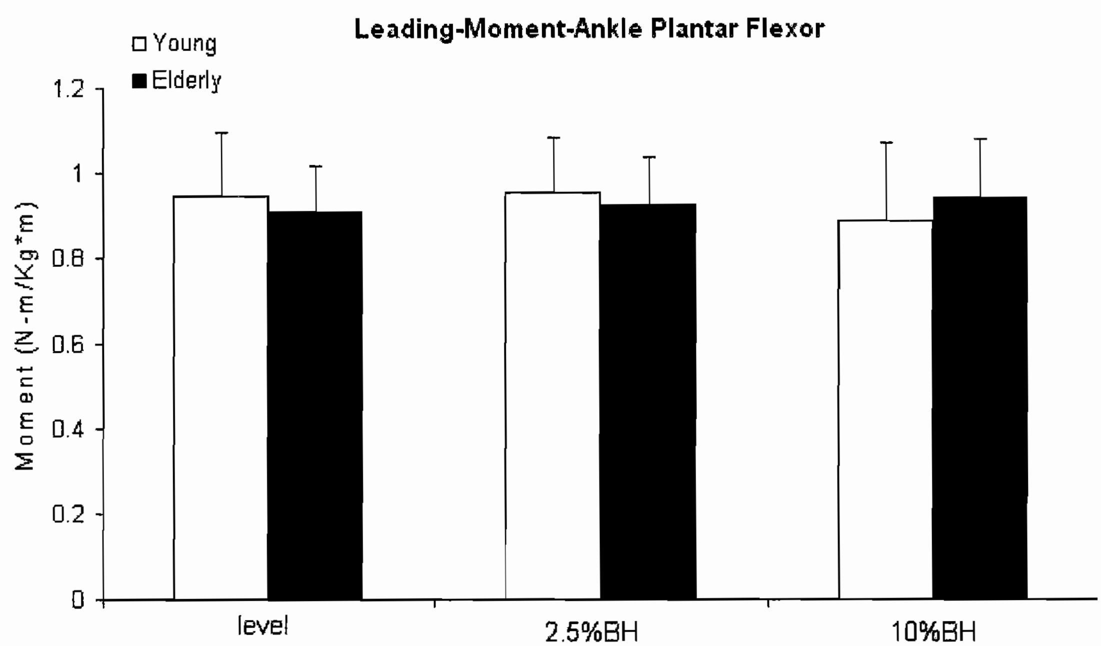


Figure 9. Peak ankle plantar flexor moment (normalized by the body height and weight) of the leading limb.

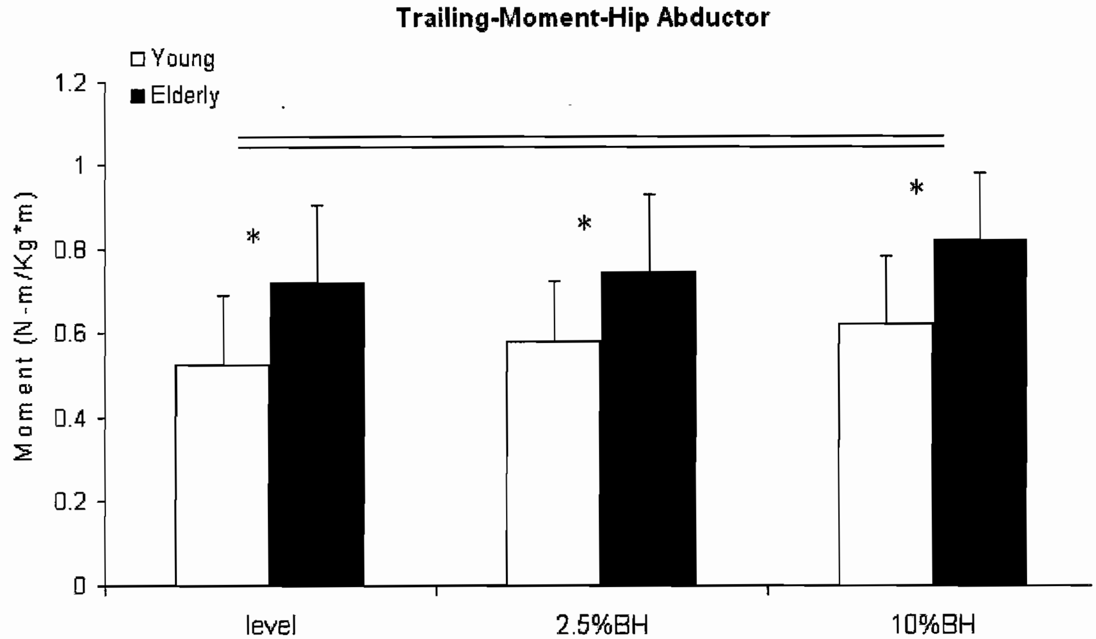


Figure 10. Peak hip abductor moment (normalized by the body height and weight) of the trailing limb. The columns shared the double bars (=) denote significant obstacle height effect ($p = 0.002$). Asterisks denote significant differences with age ($*p < 0.05$).

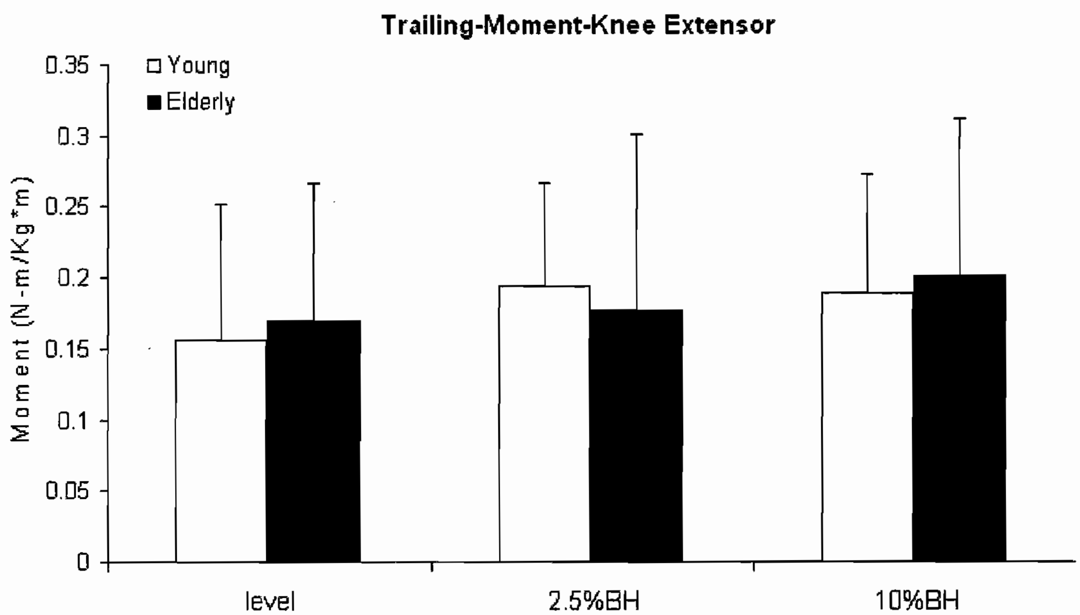


Figure 11. Peak knee extensor moment (normalized by the body height and weight) of the trailing limb.

Figure 12. Peak ankle plantar flexor moment (normalized by the body height and weight) of the trailing limb. . The columns shared the double bars (=) denote significant obstacle height effect ($p = 0.001$).

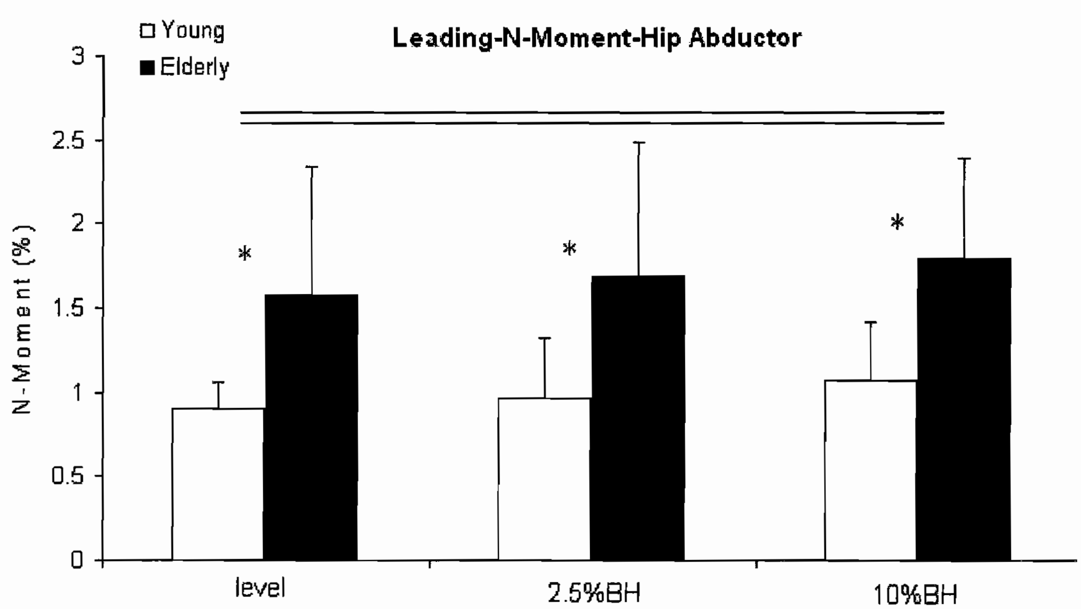


Figure 13. Peak hip abductor N-moment (normalized by the maximum moment of MVC) of the leading limb. The columns shared the double bars (=) denote significant obstacle height effect ($p = 0.024$). Asterisks denote significant differences with age ($*p < 0.05$).

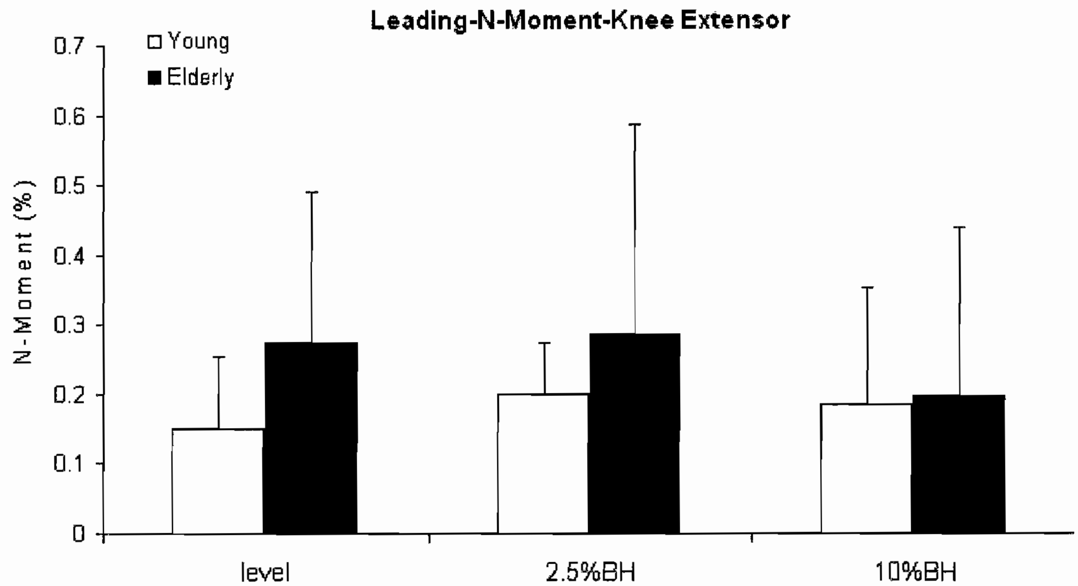


Figure 14. Peak knee extensor N-moment (normalized by the maximum moment of MVC) of the leading limb.

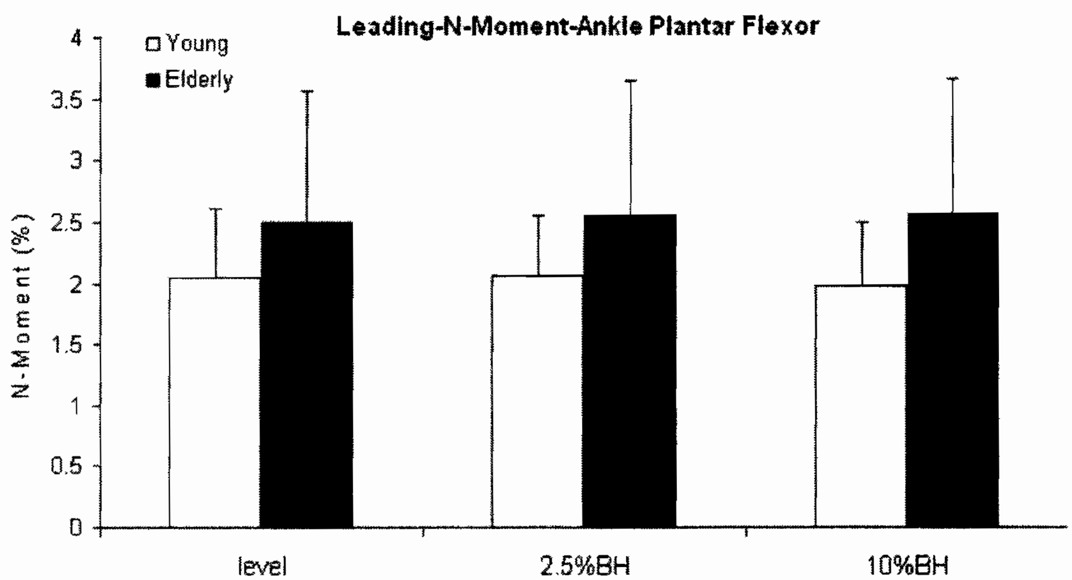


Figure 15. Peak ankle plantar flexor N-moment (normalized by the maximum moment of MVC) of the leading limb.

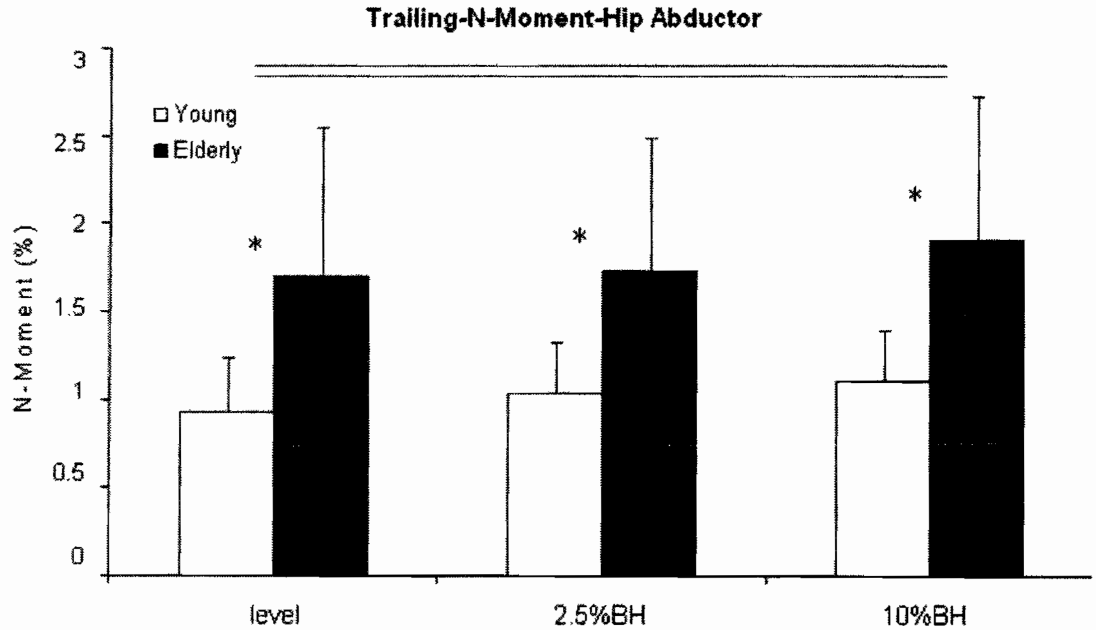


Figure 16. Peak hip abductor N-moment (normalized by the maximum joint moment of MVC) of the trailing limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p = 0.002$). Asterisks denote significant differences with age ($*p < 0.05$).

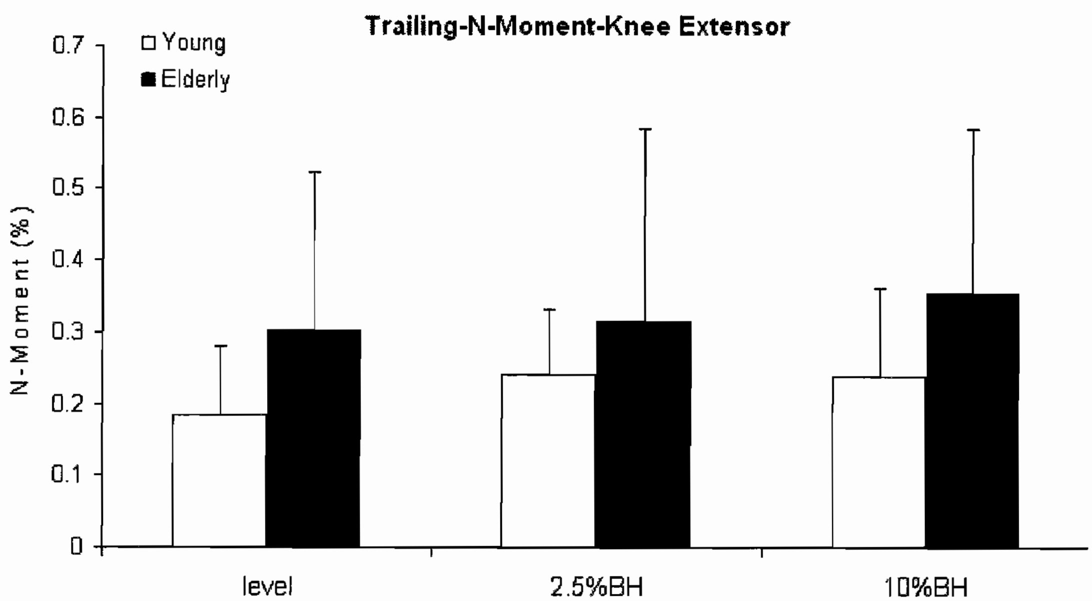


Figure 17. Peak knee extensor N-moment (normalized by the maximum moment of MVC) of the trailing limb.

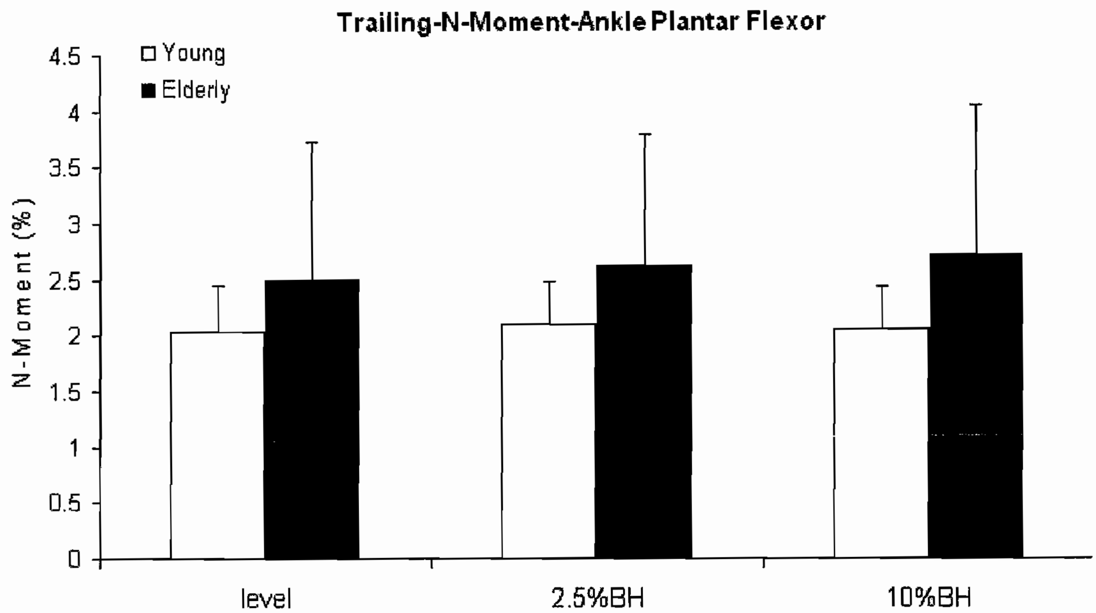


Figure 18. Peak ankle plantar flexor N-moment (normalized by the maximum moment of MVC) of the trailing limb.

Electromyography Data

Typical processed EMG activation patterns of the GM, VL, ST, and GA muscles of the trailing limb during a level walking trail are presented in Figures 19, 20, 21 and 22, respectively. Similar patterns were found for the leading limb and during the obstacle crossing trails. The greatest activation of the GM was found during the weight acceptance phase (Phase I) for the trailing limb, and it remained active through the single stance phase and ceased activation before the opposite limb begins to bear weight. This pattern matched the functional role of the GM, which is the main hip abductor to counterbalance the external adduction moment generated by the body weight and to prevent the pelvic drop of the unsupported side. The VL started to activate from the late swing phase, reaching its greatest activation also during the weight loading of the support limb and kept activating until approximately 20 % of the gait cycle. This demonstrates that the VL takes a role to stabilize the knee while loading the body weight on the support limb. The ST began activating at approximately 80 % of gait cycle and continued the activation around 5 % of the gait cycle. The low level activation (10% of MVC) of the ST during initial contact serves as a useful protective flexion force. The early termination of the ST activity by mid loading response implies that the role of this muscle is primarily protection from potential hypertension. The activation of GA was found during single stance phase of the supporting limb which was between around 20 % and 50 % of gait cycle and the highest activation was at the terminal stance. This can be understood because the GA first contracts eccentrically, which controls the forward movement of the tibia over the fixed foot. After that, the gastrocnemius undergoes a concentric contraction which initiates plantar flexion for toe-off.

Age group and obstacle height effect on the mean N-EMG ratios of the ST, GM, VL, and GA were examined. The EMG data of the AM were not further analyzed due to the noisy signal found in most elderly adults. For the scope of this study, the mean N-EMG ratios were analyzed but not presented here. Compare to young adults, elderly adults showed significantly greater N-EMG ratios in all 4 muscles of the trailing limb (Figure 27-30). When changing the testing limb as leading limb, elderly adults demonstrated significantly greater GM, VL, and ST N-EMG ratios than young adults (Figure 23-25). However, there was no significant age group difference in the GA N-EMG ratios of the leading limb (Figure 26). Increasing obstacle height resulted in significantly greater N-EMG ratios for all muscles in both the trailing and leading limbs (Figure 23-30).

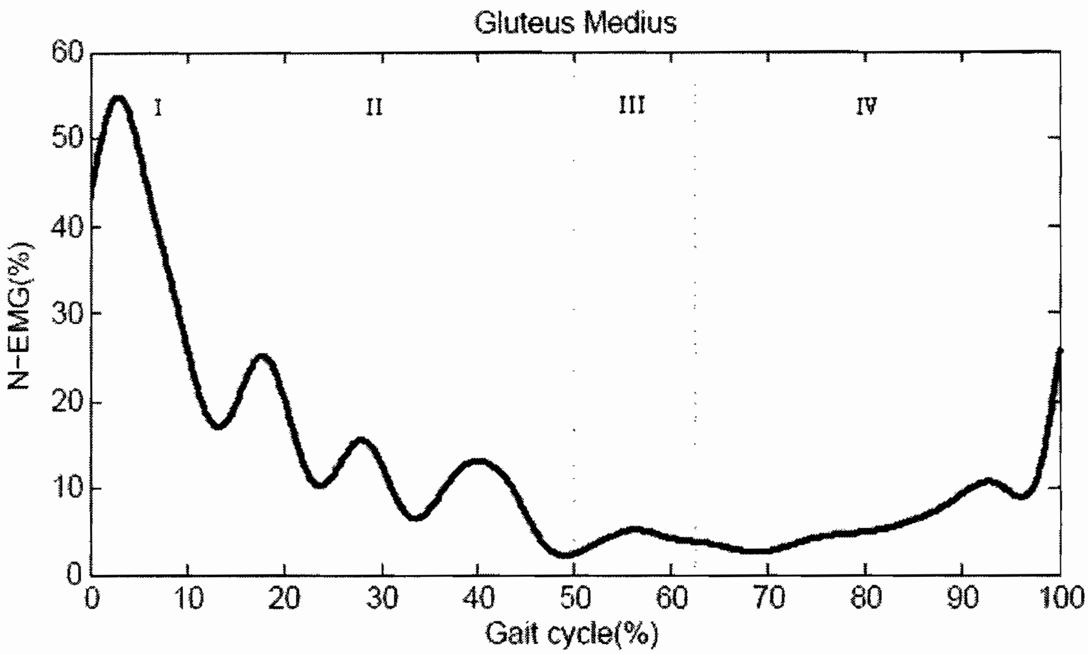


Figure 19. Gluteus medius normalized EMG activation ratio in a gait cycle of the trailing limb.

Phase I: THS-LTO; Phase II: LTO-LHS; Phase III: LHS-TTO; Phase IV: TTO-THS

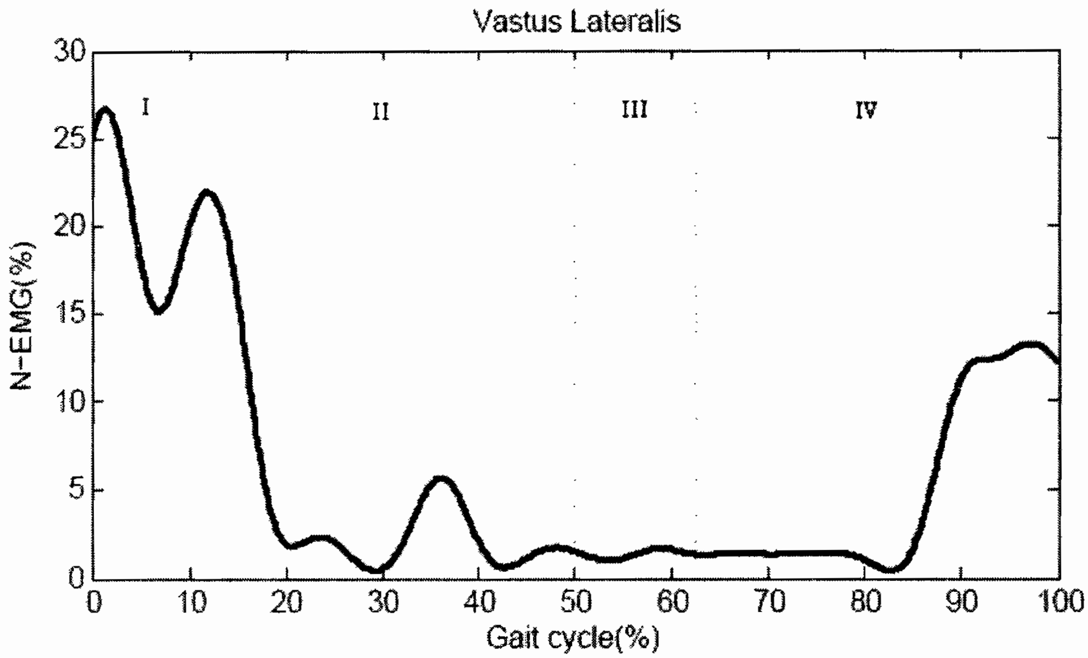


Figure 20. Vastus lateralis normalized EMG activation ratio in a gait cycle of the trailing limb

Phase I: THS-LTO; Phase II: LTO-LHS; Phase III: LHS-TTO; Phase IV: TTO-THS

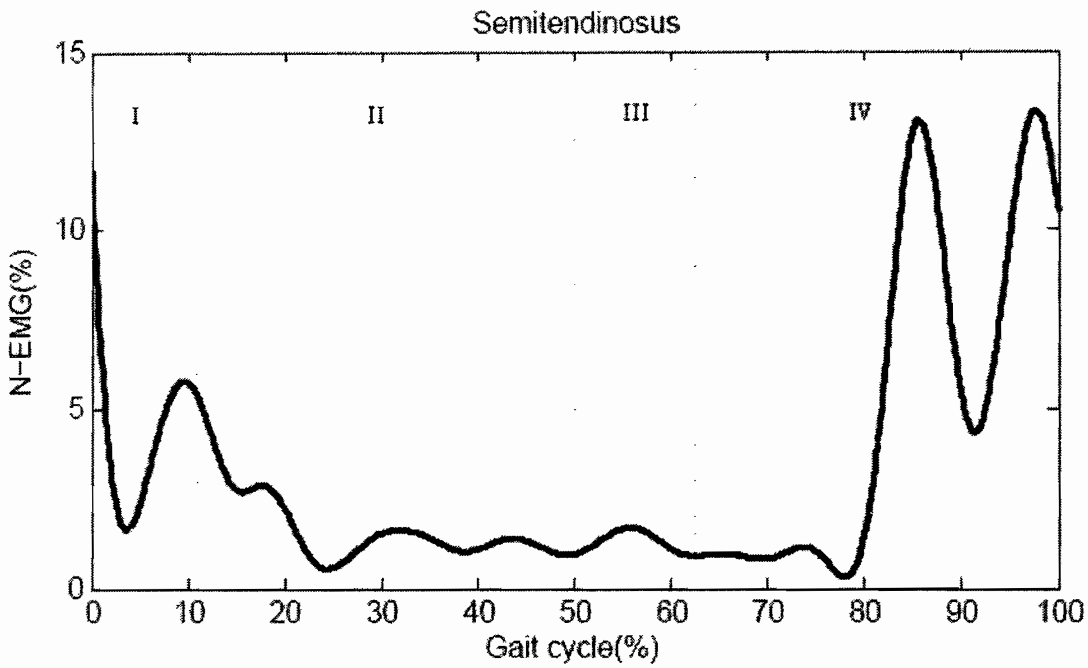


Figure 21. Semitendinosus normalized EMG activation ratio in a gait cycle of the trailing limb.

Phase I: THS-LTO; Phase II: LTO-LHS; Phase III: LHS-TTO; Phase IV: TTO-THS

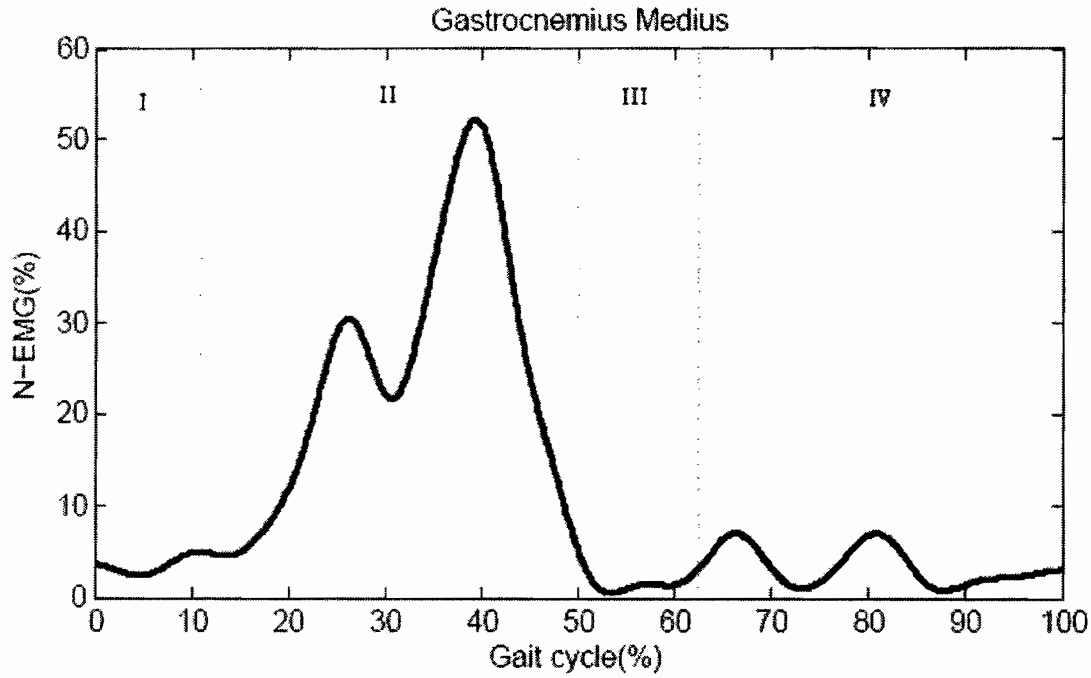


Figure 22. Gastrocnemius medius normalized EMG activation ratio in a gait cycle of the trailing limb.

Phase I: THS-LTO; Phase II: LTO-LHS; Phase III: LHS-TTO; Phase IV: TTO-THS

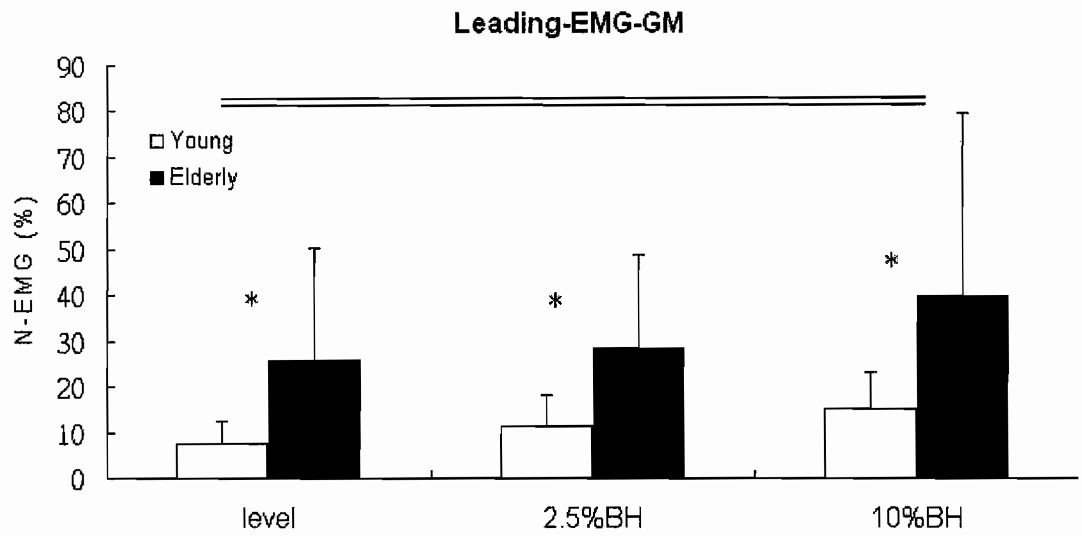


Figure 23. Mean Gluteus medius normalized EMG activation ratio during single stance phase (phase III) of the leading limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p = 0.043$). Asterisks denote significant differences with age ($*p < 0.05$).

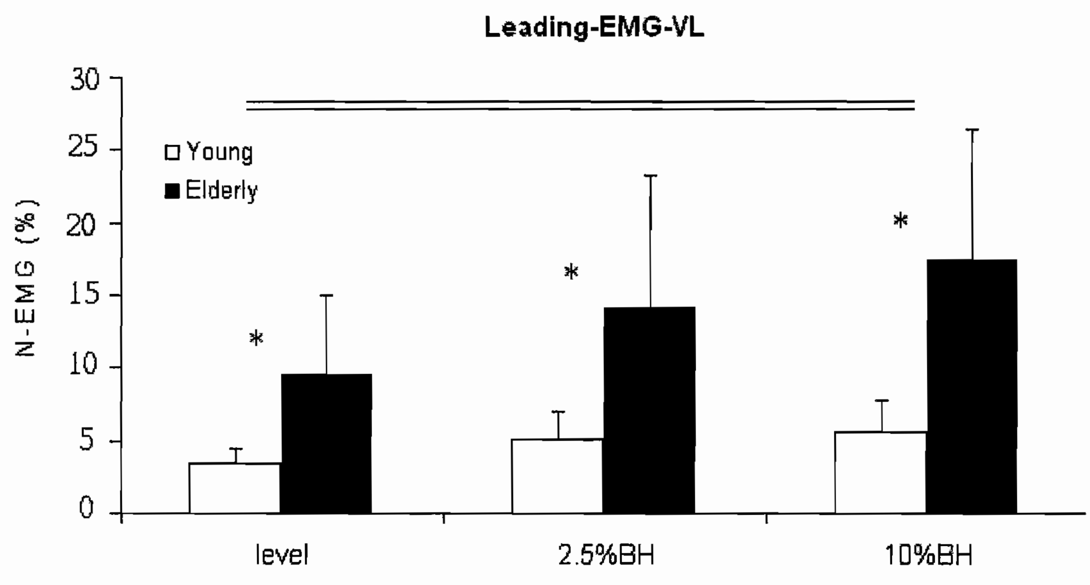


Figure 24. Mean vastus lateralis normalized EMG activation ratio during single stance phase (phase III) of the leading limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p < 0.001$). Asterisks denote significant differences with age ($*p < 0.05$).

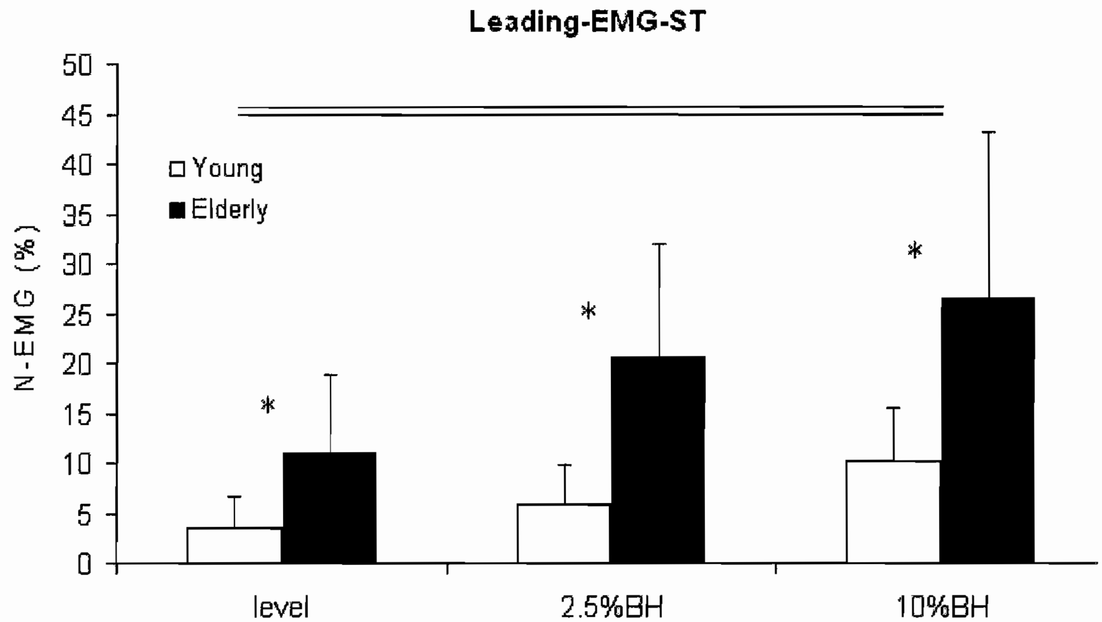


Figure 25. Mean semitendinosus normalized EMG activation ratio during single stance phase (phase III) of the leading limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p < 0.001$). Asterisks denote significant differences with age (*$p < 0.05$).

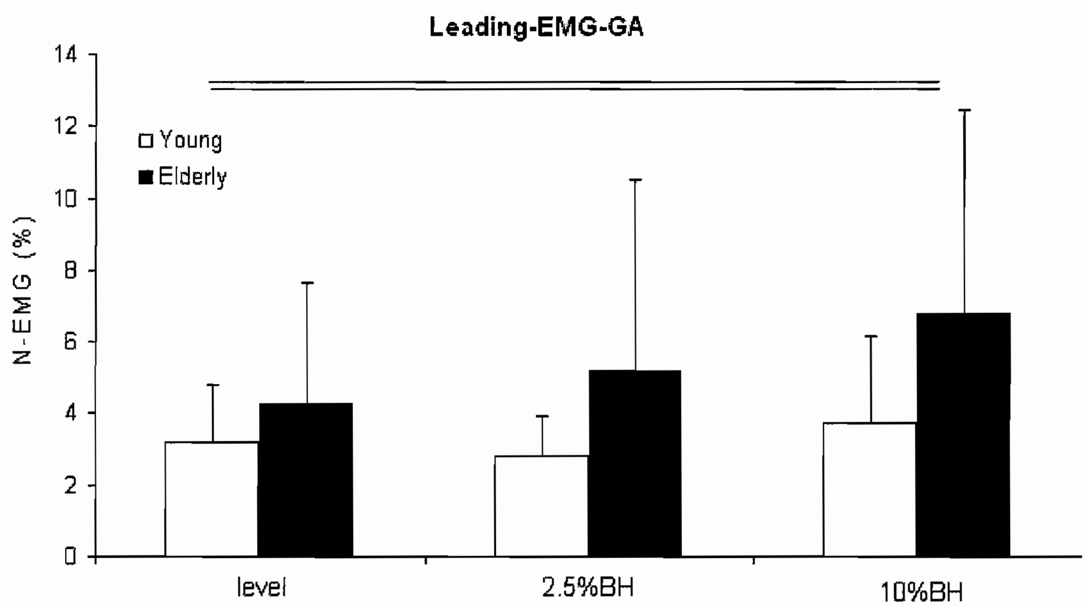


Figure 26. Mean gastrocnemius normalized EMG activation ratio during double stance phase (phase IV) of the leading limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p = 0.002$).

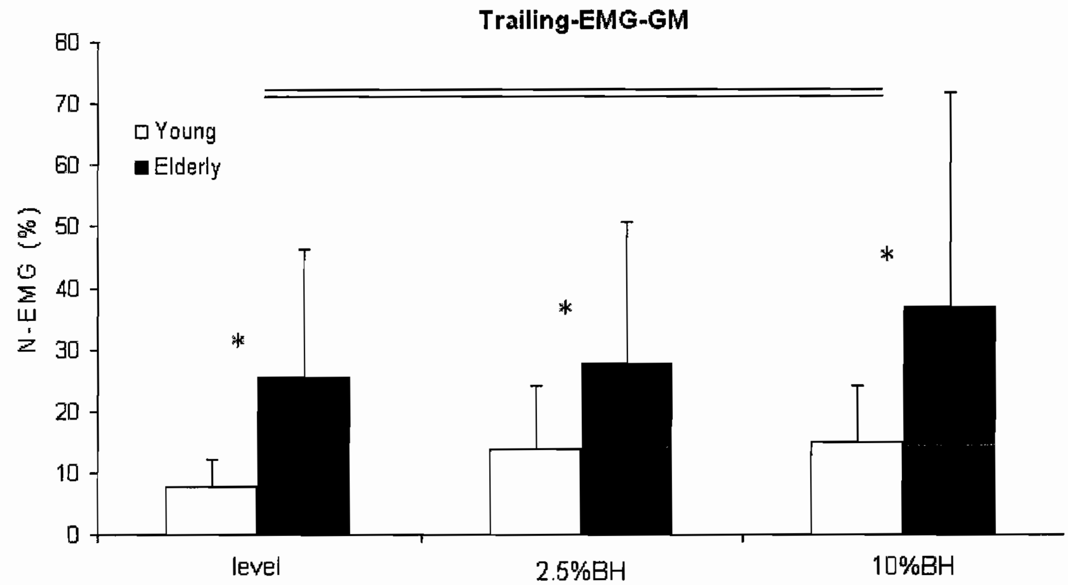


Figure 27. Mean gluteus medius normalized EMG activation ratio during single stance phase (phase II) of the trailing limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p = 0.01$). Asterisks denote significant differences with age ($^*p < 0.05$).

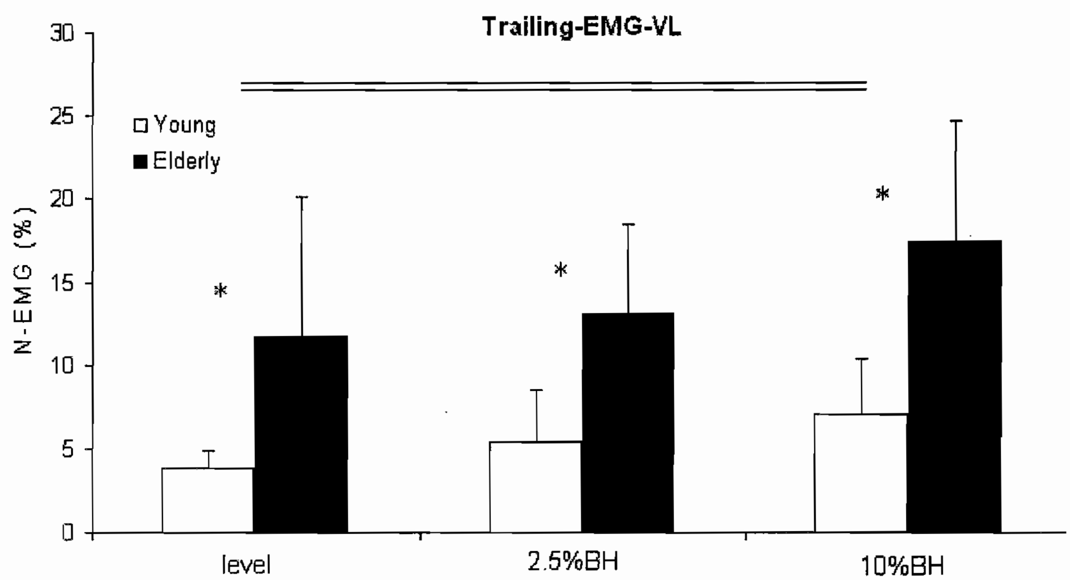


Figure 28. Mean vastus lateralis normalized EMG activation ratio during single stance phase (phase II) of the leading limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p < 0.001$). Asterisks denote significant differences with age ($^*p < 0.05$).

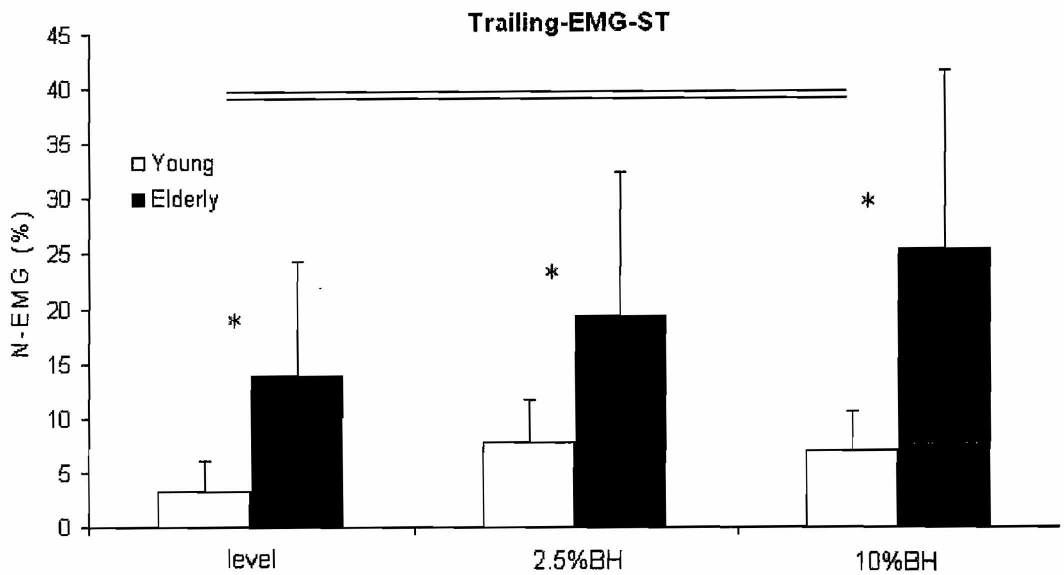


Figure 29. Mean semitendinosus normalized EMG activation ratio during single stance phase (phase II) of the trailing limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p < 0.001$). Asterisks denote significant differences with age ($*p < 0.05$).

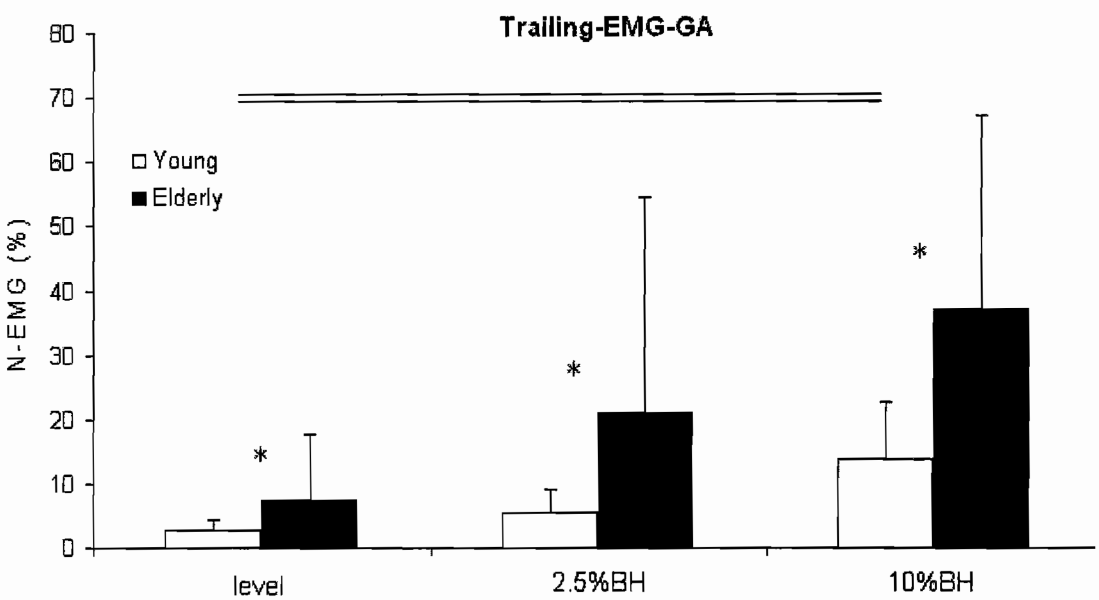


Figure 30. Mean gastrocnemius normalized EMG activation ratio during double stance phase (phase III) of the trailing limb. The columns sharing the double bars (=) denote significant obstacle height effect ($p = 0.002$). Asterisks denote significant differences with age ($*p < 0.05$).

CHAPTER IV

DISCUSSIONS

Our hypotheses were confirmed by the results. First, both the N-EMG and N-moment ratios demonstrated similar trends in response to the increasing obstacle height. Except for the knee extensor N-moment ratio of the leading limb, these two ratios increased as the obstacle height increases. Second, elderly adults exhibited higher N-EMG and N-moment ratios than young adults during all walking tasks, especially for the N-EMG and N-moment ratios of the hip abductors. Elderly adults demonstrated a significantly smaller isometric hip abductor moment, which could imply a smaller capacity in muscle force generation. When performing a task that requires similar mechanical efforts, compared to young adults, elderly adults would encounter a greater challenge. Therefore, it is reasonable to expect that N-EMG or N-moment ratios are significantly greater in the elderly during walking and obstacle crossing. Third, the findings suggest that when a strong co-activation between agonist and antagonist muscles is present, using N-EMG ratio could provide a better quantification of muscular challenges. Detailed explanation of this conclusion will be addressed in the following paragraphs.

Temporal-Distance Gait Measurements

In agreement with the previous studies (Chou, Kaufman, Haun, & Brey, 2003; Hahn et al., 2005; Lee & Chou, 2006), the gait velocity in both age groups decreased significantly when stepping over a higher obstacle during gait. However, it was unexpected, in this current study, that the gait velocity of elderly adults was not significantly lower than that of young adults. This could be explained by the high activity level of these older individuals. Elderly subjects in this study might represent a more physically-fit section of the broader elderly population. It is possible that a group of less active elderly adults would demonstrate significantly slower walking velocity. Another explanation could be due to the small sample size of this study. Larger groups of subjects might demonstrate significant age effect.

Joint Moments during Gait

Previous researchers (Chou & Draganich, 1997; Chen & Lu, 2006) reported significant obstacle height effects on the peak knee extensor and ankle plantar flexor moments of the trailing limb. Similarly, several of the peak joint moments in this study were found to be greater than those found during unobstructed level walking. However, only the peak hip abductor moment of the trailing limb reached statistically significance. Since the trend of increasing peak moments of knee extensor and ankle plantar flexor (except knee extensor moment in the leading limb) with obstacle height increase was observed in this study, it is likely that increasing sample size would result in significant obstacle height effect in those moments. In addition, during the single stance phase, it is important for the hip abductor of the supporting limb to counter balance the moment generate by the body weight about the supporting hip. Furthermore, it was recently revealed that elderly adults with balance impairment showed greater range of medio-lateral center of mass motion (Chou et al, 2003). Greater range of medio-lateral center of mass motion would create a larger demand on hip abductors. These results might indicate that the challenge of the obstacle height imposed on the hip abductor muscles was higher than those on the knee extensors and ankle plantar flexors of the supporting limb.

These greater demands on the hip abductor muscles may be a contributing factor to sideways falls in those elderly having decreased abductor muscle strength.

Significant age effects were found in the hip abduction peak joint moment and N-moment value for both the leading and trailing limbs. Since joint moments were generated mainly by muscles, these results suggested that more muscular efforts in hip are required for the elderly adults to complete the same task than young adults.

Normalized EMG Activation Ratios during Gait

Significant muscle strength declines as we age. In this study, the isometric muscle strength measured during MVC showed an age-related reduction in all muscle groups tested (Table 2), although it did not reach statistically significant for the ankle plantar flexor (p = .403). This could be due to the fact that the isometric ankle plantar flexor moment was measured in a sitting position, which might limit the subject's ability to generate his or her maximum effort. Another explanation for this could be the relatively active lifestyles of our elderly subjects.

The mechanical challenges of obstacle crossing are the same for both elderly and young adults given that they walked with a similar gait velocity in this study. However, elderly adults were found to demonstrate greater N-EMG values than young adults during all gait conditions. Considering that the maximum strength in elderly adults has been reported to be lower, it is reasonable to expect that elderly adults will use a greater percentage of their neuromuscular capacity to successfully walk and cross over an obstacle. This suggests that the N-EMG ratios could sensitively account for both increasing muscular demand during obstacle crossing as well as declines in muscle strength capacity due to aging.

Mean N-EMG vs. Peak N-moment

Instead of calculating the average joint moment over each of the gait phases, the peak moment of each selected joint function was selected for analysis. This is because that the net joint moment represents the all the muscular efforts about a joint. During a defined gait phase, the net moment could change from one direction to the other. Thus, the average moment across a gait phase could inaccurately demonstrate the true demand imposed to muscles about a joint. To better compare with the moment data, the average N-EMG values across the gait phase which the peak joint moment occurred were selected for analysis in this study.

Both GM N-EMG and hip abductor N-Moment ratios were able to sensitively detect the increasing challenges imposed on both young and elderly adults when stepping over a higher obstacle. However, the leading limb knee extensor moment was found to significantly decrease with the increasing obstacle height from 2.5%BH to 10%BH. This pattern was in agreement with those reported previously (Chen, 2006; Lee, 2005). However, in the present study, the N-EMG ratios of VL and ST increased linearly with the increase of obstacle height. This finding suggests that the muscular demand on the knee muscles are not diminishing as indicated by the leading limb knee extensor moment. Previous studies have reported that co-activation of agonist and antagonist muscles participate in the regulation of joint stiffness (Baratta et al, 1988). The EMG activation pattern of ST in this study lasted from late swing phase to early stance phase. In addition, N-EMG ratios of both ST and VL of the leading limb were found to significantly increase as the obstacle height increases. This provides the evidence of intensified co-activation between knee extensors and flexors during early weight acceptance phase of the leading limb after crossing over an obstacle. Therefore, the use of net joint moments could underestimate the muscular challenge imposed to an individual when strong co-activation of agonist and antagonist muscles are present.

Furthermore, almost all N-EMG values we tested could demonstrate age group and obstacle height differences, while only hip abductor N-moment data showed significant differences between the young and older adults. This might indicate that the N-EMG values might not only provide a better detection of the elderly than the N-moment value but also sensitively reflect the increasing challenge from a higher obstacle. Since EMG data are direct measures from muscle activations, it might provide more insightful information on the quantification of muscular challenge than the net joint moments, which are calculated from several estimation techniques.

Limitations of this Study

Small sample size is one of the limitations in this study. It could have resulted in a large variation in each of the parameters and affected outcomes of our statistical analysis. However, the small sample size did not restrict findings of significant group differences in most N-EMG values and the hip abductor moments. Therefore, a larger sample size will probably enhance the results.

Another limitation of this study could be that the testing position of the maximum isometric contraction at ankle joint might limit the subject's ability to generate his or her maximum strength, although verbal encouragement was given to subjects during the MVC testing. The third limitation of this study exists in elderly adults having more adipose tissues over the GM and loosening skin over the AM. However, confirmation procedures were taken prior to testing to ensure EMG electrodes were able to pick up the GM and AM activation by asking the subject to perform voluntary contraction.

Future Studies and Clinical Implications

Findings of this study suggest that, compared to young adults, higher demands were imposed to lower extremity muscle during unobstructed and obstructed gait in the elderly. This may lead to easily muscle fatigue during daily locomotion and place elderly individuals at higher risk for falling or tripping.

Although muscle weakness appears to be an independent risk factor for falls, there is no strong evidence to support strength training an effective prevention (Moreland et al, 2004). Furthermore, the threshold of the strength training of a specific muscle group is also required to be investigated. Future studies are needed to examine the effectiveness of strength training program and design a specific type of exercise to better prevent falls in the elderly. The findings in this study suggest that the challenge of the obstacle height imposed on the hip abductor muscles was higher than those on the knee extensors and ankle plantar flexors of the supporting limb. These greater demands on the hip abductor muscles may be related to sideways falls in those elderly having decreased abductor muscle strength. Therefore, the relationship between strengthening the hip abductor and fall prevention in elderly adults is worth to evaluate. In addition, when quantifying muscular demands in a specific muscle group during walking or walking related tasks, compared to the joint moment data, the data obtained from EMG may be better account for the co-contraction phenomenon.

APPENDIX A

SUBJECT INFORMED CONSENT FORM

CONSENT FORM

Research Project Title: Detecting and Simulating Falls Risk in the Elderly

You are invited to participate in a research study conducted by Dr. Li-Shan Chou, of the University of Oregon, Department of Human Physiology. We hope to gain a better understanding of the mechanisms underlying the increased incidences of falls in the elderly and factors that are important for the maintenance of balance during walking. This research project is currently sponsored by the National Institutes of Health.

If you decide to participate, you will be examined and tested in the Motion Analysis Laboratory (Room B52, Gerlinger Annex). First, in order to make sure that you are qualified for being a research subject of this research study, we will arrange a physical screening for you in the Motion Analysis laboratory with Victor Lin, MD (Rehabilitation Medicine Associates of Eugene-Springfield, P.C.). Dr. Lin will briefly ask about your current health condition, perform a neurological examination, and document any age-related deficits in sensory motor functions (including vision, inner ear function, and sensation). We expect that the clinical visit will take approximately 45 minutes. Dr. Lin will determine whether you can be included in this study.

In order to be included in this study you must not have had (1) any histories of significant head trauma, (2) neurological or musculoskeletal diagnosis that could account for possible imbalance and falls, such as a history of cerebrovascular accident, Parkinson's disease, post-polio syndrome, cardiac problems, transient ischemic attacks, or lower-extremity amputation and joint replacements, or (3) visual impairment not correctable with lenses. Also, you will be tested to exclude substantial cognitive impairment as suggested by a mean Mini-Mental Status score of 24 or higher. Furthermore, you will be categorized in the faller group if you have experienced two or more falls within the 6 months prior to the study.

You will not be responsible for the payment related to your examination by Dr. Lin under this study. Any information that is obtained in connection with this clinical visit will remain confidential and will be disclosed only when you are qualified as a study subject and with your permission as granted in this consent form and its attachment. If you are not qualified as a research subject of this study, all of your information collected by Dr. Lin will be discarded immediately after our review. In order to do this research, you must also authorize us to access and use the above health information. An authorization form to allow Dr. Lin to release that health information is attached for you to review and sign as an addendum to this consent form. The purpose of the form entitled "Authorization Form for Research Disclosure of Personal Health Information" is to allow Dr. Lin to share medical history and exam results with Dr. Chou.

The laboratory testing will include three sections. First, your body movement will be recorded by our motion capture cameras (or maybe video cameras with your approval) while you walking with barefoot along a 10-m walkway, step over an obstacle, and continue walking along the walkway. The obstacle is made of two adjustable upright standards and a plastic pipe two meters in length and set to a height similar to a curbstone (~ 6 inches). Both reflective markers and surface electrodes will be placed on your skin at selected bony landmarks and muscle surfaces to record the motion of each individual body segment and the muscle activity of three muscles from both legs.

Before any walking trial, electromyographic (EMG) data of each selected muscle group (medial gastrocnemius, vastus lateralis, and gluteus medius) will be recorded during a manual muscle testing (MMT) to register the maximum EMG activity of each muscle group. When testing the gluteus medius muscle, you will be instructed to lie on their side, facing away from the examiner. The starting position will be fixed at 30° of hip abduction with slight extension and external rotation. The examiner will apply pressure near the ankle in the direction of adduction and slight hip flexion, with the other hand placed posteriorly on the iliac crest to maintain pelvic position. During vastus lateralis testing, you will be instructed to sit at the table edge with lower legs freely suspended. One examiner's hand will be placed between the posterior thigh and the table as supportive cushion. The other hand will be placed on the distal end of the shank, applying pressure in the direction of knee flexion. Knee angle will be fixed at 45°. You will be instructed to grip the edge of the table to maintain upright posture during the test. For the medial gastrocnemius, you will be instructed to lie in prone position with lower legs extending past the table edge and one foot placed firmly against the wall. This testing position will maintain full knee extension and allow isolated ankle plantar flexion against the wall (similar to a one-legged heel-raise).

You will also be tested on a muscle strength testing device to measure your muscle strength at the hip, knee, and ankle joints of both legs. Strength of your hip abductor will be measured in a standing position using a frame with a padded adjustable height board with arm supports that allow subjects to stand with support for testing. You will be instructed to abduct the hip against the application pad without rotating the lower extremity or moving the trunk. Strength of the knee extensor will be measured in a seated position at 60 degrees of knee flexion, and strength of the ankle plantar flexor will be measured in a seated position at 20 degrees of knee flexion and neutral ankle position. To stabilize the trunk during testing Velcro straps will be tightened across the chest and anterior superior iliac spines, in addition to tilting of the chair 10° backward from the horizontal. You will be instructed to push as hard as you can for a period of 5 seconds, or until the torque curve plateaued for 2 seconds as visualized on the monitor. A rest period of 30 seconds or longer will be given between repetitions.

You will be asked to wear a pair of paper physical therapy shorts and sleeveless shirt (tank top) during testing. It will take approximately 3 hours to perform all of the above-mentioned tests.

We expect that there will be no more risk for you during testing than there normally is for you when outside of the laboratory. However, you may feel fatigue during or after muscle strength testing. Our staff member will check with you frequently and provide any required assistance. You will be given frequent breaks as requested. There is also possibility of discomfort involved in removing adhesive tape (used for marker placement) from skin at the end of the experiment. Although you personally will not receive any benefits from this research, based on results of this study more effective therapies, rehabilitation programs, or balance assistive devices for the prevention of falls in the elderly may be designed and implemented.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Subject identities will be kept confidential by coding the data as to study, subject pseudonyms, and collection date. The code list will be kept separate and secure from the actual data files. Furthermore, all videotaped data (collected upon your approval) will be kept confidential and will be reported in an anonymous fashion (with my face masked). The videotapes will be erased after an appropriate period of time after the completion of the study.

No financial compensation will be offered for your participation. However, you will be provided with a free physical screening to your sensory motor functions (including vision, inner ear function, and sensation). Your participation is voluntary. Your decision whether or not to participate will not affect your relationship with the Department of Human Physiology or University of Oregon. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without penalty.

If you have any questions, please feel free to contact Dr. Li-Shan Chou, (541) 346-3391, Department of Human Physiology, 112C Esslinger Hall, University of Oregon, Eugene OR, 97403-1240. If you have questions regarding your rights as a research subject, contact Human Subjects Compliance, University of Oregon, Eugene, OR 97403, (541) 346-2510. You will be given a copy of this form to keep. Your signature indicates that you have read and understand the information provided above, understand the procedures that you will be experiencing, and willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you will receive a copy of this form, and that you are not waiving any legal claims, rights or remedies.

Name: ______________________________

Signature: ______________________________

Date: ______________________________

APPENDIX B

BERG BALANCE SCALE

PATIENT ________________ DATE ____________

1. SIT TO STAND

INSTRUCTIONS: Please stand up. Try not to use your hands for support.

() 0 Needs moderate or maximal assist to stand

() 1 Needs minimal assist to stand or to stabilize

() 2 Able to stand using hands after several tries

() 3 Able to stand independently using hands

() 4 Able to stand with no hands and stabilize independently

2. STANDING UNSUPPORTED

INSTRUCTIONS: Stand for two minutes without holding.

() 0 Unable to stand 30 seconds unassisted

() 1 Needs several tries to stand for 30 seconds unsupported

() 2 Able to stand 30 seconds unsupported

() 3 Able to stand 2 minutes with supervision

() 4 Able to stand safely for 2 minutes

IF SUBJECT IS ABLE TO STAND 2 MINUTES SAFELY SCORE FULL MARKS FOR SITTING UNSUPPORTED. PROCEED TO #4.

3. SITTING UNSUPPORTED WITH FEET ON FLOOR

INSTRUCTIONS: Sit with arms folded for two minutes.

() 0 Unable to sit without support for 10 seconds

() 1 Able to sit for 10 seconds

() 2 Able to sit for 30 seconds

() 3 Able to sit for two minutes under supervision

() 4 Able to sit safely and securely for 2 minutes

4. STANDING TO SITTING

INSTRUCTIONS: Please sit down.

() 0 Needs two people to assist or supervise to be safe

() 1 Needs assistance to sit

() 2 Uses back of legs against chair to control descent

() 3 Control descent by using hands

() 4 Sits safely with minimal use of hands

5. TRANSFERS

INSTRUCTIONS: Please move from chair without arm rests to a chair with armrests and back.

() 0 Needs two people to assist or supervise to be safe

() 1 Needs one person to assist

() 2 Able to transfer with verbal cueing and/or supervision

() 3 Able to transfer safely with use of hands

() 4 Able to transfer safely with minor use of hands

6. STANDING UNSUPPORTED WITH EYES CLOSED

INSTRUCTIONS: Stand with your eyes closed for 10 seconds.

() 0 Needs help to keep from falling

() 1 Unable to keep eyes closed for 3 second s nut stays steady

() 2 Able to stand for 3 seconds

() 3 Able to stand for 10 seconds with supervision

() 4 Able to stand for 10 seconds safely

7. STANDING UNSUPPORTED WITH FEET TOGETHER

INSTRUCTIONS: Place you feet together and stand without holding

() 0 Needs help to attain position and unable to hold for 15 seconds

() 1 Needs help to attain position but able to stand for 15 seconds

() 2 Able to place feet together independently but unable to hold for 30 seconds

() 3 Able to place feet together independently and stand for 1 minutes with supervision

() 4 Able to place feet together independently and stand for 1 minute safely

THE FOLLOWING ITEMS ARE TO BE PERFORMED WHILE STANDING UNSUPPORTED

8. REACHING FORWARD WITH OUTSTRETCHED ARM

INSTRUCTIONS: Lift arm to 90°. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at the end of fingertips when arm is at 90°.

Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the fingers reach while the subject is in the most forward lean position.)

() 0 Needs help to keep from falling

() 1 Reaches forward but needs supervision

() 2 Can reach forward > 2 inches safely

() 3 Can reach forward > 5inches safely

() 4 Can reach forward confidently > 10 inches

9. PICK UP OBJECT FROM THE FLOOR

INSTRUCTIONS: Pick up the shoe/slipper that is placed in front of your feet.

() 0 Unable to try / needs assist to keep from falling

() 1 Unable to pick up, and needs supervision while trying

() 2 Unable to pick up but reaches 1-2 inches from slipper and keeps balance independently

() 3 Able to pick up slipper but needs supervision

() 4 Able to pick up slipper safely and easily

10. TURNING TO LOOK OVER LEFT AND RIGHT SHOULDERS

INSTRUCTIONS: Turn your upper body to look over your left shoulder, then your right shoulder.

() 0 Needs assist to keep from falling

() 1 Needs supervision when turning

() 2 Turns sideways only but maintains balance

() 3 Looks behind one side only, other side shows less weight shift

() 4 Looks behind from both sides and weight shifts well

11. TURN 360 DEGREES

INSTRUCTIONS: Turn all the way around to your left and then turn all the way around to the right.

() 0 Needs assistance while turning

() 1 Needs close supervision or verbal cueing

() 2 Able to turn 360 safely but slowly in both directions

() 3 Able to turn 360 safely one side only < 4 seconds, the other side is > 4 seconds

() 4 Able to turn 360 safely in < 4 seconds each side

DYNAMIC WEIGHT SHIFTING WHILE STANDING UPSUPPORTED

12. COUNT NUMBER OF TIMES STEP TOUCH MEASURED STOOL
INSTRUCTIONS: Place each foot alternately on the stool until each foot has touched 4 times.
() 0 Needs assistance to keep from falling / unable to try
() 1 Able to complete > 2 steps, needs minimal assistance
() 2 Able to complete 4 steps without aid, but with supervision
() 3 Able to stand independently and complete 8 steps > 20 seconds
() 4 Able to stand independently and safely and complete 8 steps in 20 seconds

13. STANDING UNSUPPORTED ONE FOOT IN FRONT
INSTRUCTIONS: (Demonstrate to subject) Place one foot directly in front of the other, or stepping far enough ahead that the heel of your forward foot is ahead of the toes of the other foot.
() 0 Loses balance while stepping or standing
() 1 Needs help to step but can hold for 15 seconds
() 2 Able to take small step independently and hold for 30 seconds
() 3 Able to place foot ahead of other independently and hold for 30 seconds
() 4 Able to place foot tandem independently and hold for 30 seconds

14. STANDING ON ONE LEG
INSTRUCTIONS: Stand on one leg as long as you can without holding.
() 0 Unable to try or needs assist to prevent fall
() 1 Tries to lift leg, unable to hold 3 seconds, but remains standing independently
() 2 Able to lift leg independently and hold > or =3 seconds
() 3 Able to lift leg independently and hold for 5-10 seconds
() 4 Able to lift leg independently and hold > 10 seconds

TOTAL SCORE MAXIMUM =56 __________

APENDIX C

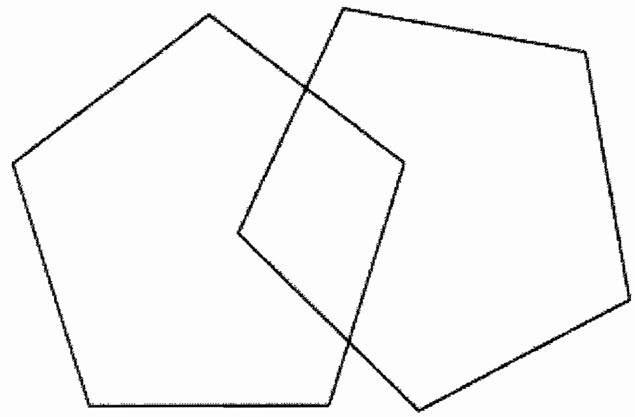
MINI MENTAL STATE TEST

The Mini-Mental State Exam

Patient________________ Examiner__________________ Date_____________

Maximum	Score	
		Orientation
5	( )	What is the (year) (season) (date) (day) (month)?
5	( )	Where are we (state) (country) (town) (hospital) (floor)?
		Registration
3	( )	Name 3 objects: PENCIL, APPLE, WATCH 1 second to say each. Then ask the patient all 3 after you have said them. Give one point for each correct answer. Then repeat them until he/she learns all 3. Count trials and record. Trials __________
		Attention and Calculation
5	( )	Serial 7's. 1 point for each correct answer. Stop after 5 answers.
		Recall
3	( )	Ask for the 3 objects repeated above. Give 1 point for each correct answer.
		Language
2	( )	Name a pencil and a watch.
1	( )	Repeat the following: "No ifs, ands, or buts."
3	( )	Follow a 3-stage command: "Take a paper in your hand, fold it in half, and put it on the floor."
1	( )	Read and obey the following: CLOSE YOUR EYES.
1	( )	Write a sentence.

1 ( ) Copy the design shown.



____ Total score

ASSESS level of consciousness along a continuum ________

Alert Drowsy Stupor Coma

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