Universidade de Aveiro
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Secção Autónoma das Ciências da Saúde da Universidade de Aveiro

Mónica Fernandes Moreira

Resistência à fadiga muscular: comparação do Martin Vigorimeter e Jamar Dinamómetro em pessoas independentes

Muscle fatigue resistance: comparison of Martin Vigorimeter and Jamar Dynamometer in community-dwelling people

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Gerontologia, ramo de especialização em Gestão de Equipamentos, realizada sob a orientação científica da Professora Doutora Assunção das Dores Laranjeira de Almeida, Professor da Escola Superior de Saúde da Universidade de Aveiro e co orientação do Professor Doutor Ivan Bautmans, Professor na Vrije Universiteit Brussel.

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Palavras-Chave Fadiga muscular; Co-ativação; EMG; Martin Vigorimeter; Jamar Dinamómetro

Resumo

Enquadramento: O critério exaustão para o diagnóstico de fragilidade é medido usualmente por questionários, que são subjetivos e dependem da perceção individual. O teste de resistência à fadiga (FR) foi desenvolvido como uma avaliação da exaustão para pessoas prostradas. No entanto, o Dinamómetro Jamar (JD) está a ser frequentemente utilizado para medir a força de preensão. Deste modo comparar os aparelhos é fundamental para compreender se a FR é análoga quando medida com os diferentes aparelhos.

Métodos: Cinquenta e quatro participantes (29 do sexo feminino e 25 do sexo masculino; com uma média de idade de 39.98 ± 18.09) que vivem independentemente na comunidade foram testados relativamente a funções musculares.

O teste de FR, que mede o tempo durante o qual a força declina para 50% do seu máximo, foi também registado por eletromiografia (EMG). O que permitiu o cálculo da co ativação do músculo antagonista e ativação do agonista, e posteriormente a comparação entre a performance do teste com cada um dos aparelhos (com controlo das variáveis de género e idade).

Resultados: A duração do teste FR é melhor quando se usa o VM do que quando se usa o JD. Em todos os momentos do teste FR a co ativação antagonista foi significativamente maior para VM em comparação com a do JD. Em contraste, o nível de ativação agonista foi significativamente maior com o JD em comparação à do VM. Durante o teste FR usando o VM, tanto a ativação do músculo agonista como a co ativação do antagonista diminuem significativamente ($p < 0,05$). Enquanto utilizando o JD apenas foi observada diminuição significativa na co ativação. O delta da co ativação antagonista entre VM e JD foi significativamente relacionado com o delta do FR entre ambos os aparelhos.

Conclusão: Os resultados sugerem que quando se utiliza o VM no teste FR induz uma exaustão muscular mais proeminente do que a utilização do JD, o que faz com que o VM seja mais adequado para medir a resistência à fadiga muscular. No entanto, estes resultados devem ser confirmados num estudo com uma população mais ampla.

Key-words Muscle fatigue; Co activation; EMG; Martin Vigorimeter; Jamar Dynamometer

Abstract

Background: For the diagnosis of frailty exhaustion is a criteria currently measured by self-reported questionnaires, which are subjective and dependent on individual perception. The FR test has been developed as a bed side objective evaluation of muscle fatigue. The test was validated for the VM. However, the JD is frequently used to measure the grip strength. So the comparison of these devices is required to understand if FR is similar when measured with both devices.

Methods: Fifty-four (29 female and 25 male; mean age: 39.98 ± 18.09) community-dwelling people were tested for muscle function.

The Fatigue resistance (FR), which is the time during that grip strength drops to 50% of its maximum, was recorded with each device and simultaneous sEMG of the forearm muscles was obtained. The (co-)activation of agonist and antagonist muscles was calculated and compared with the differences between the performances with each device (controlling for gender and age).

Results: FR was significantly better when measured with VM compared to JD. At all phases of the FR-test the antagonist muscle co-activation was significantly higher for VM compared to JD. In contrast, the agonist muscle activation level was significantly higher in JD compared to VM. When performing the FR-test with VM, both the agonist muscle activation and antagonist muscle co-activation decreased significantly ($p<0.05$). Whereas when using the JD, only a significant decrease in the antagonist muscle co-activation was observed. The difference in antagonist muscle activation between VM and JD was significantly related to the difference in FR between both devices.

Conclusion: The results suggest that the FR-test when using the VM induces a more prominent muscle exhaustion than when using the JD, which makes the VM more suitable for measuring muscle fatigue resistance. However, these findings must be confirmed in a larger study population.

Abbreviations or acronyms

ATP - Adenosine triphosphate

EMG – Electromyography

Ext - Extensor

EWGSOP- European Working Group on Sarcopenia in Older People

F - Force

FR- Fatigue resistance

JD – Jamar Dynamometer

Max – Maximum

mV- millivolt

MVC's - Muscular Voluntary Contractions

MVMA- Maximal Voluntary Muscle Activation

RMS- Root Mean Square

SD – Standard Deviation

T100%-Time of the maximum value

T75% - Time of 50% of the maximum value

T50% - Time of 50% of the maximum value

VM – Martin Vigorimeter

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1. Introduction

The world population of 60 years and older has doubled since 1980 and is forecast to reach 2 billion by 2050 (1). A positive aspect is that the number of older people who live dependently increases and is estimated to quadruple by 2050 in developing countries (1). This quick and dramatic demographic change has substantial implications for planning and providing health and social care. A major thread for independency at higher age is frailty. Frailty is a complex geriatric syndrome characterised by a state of increased vulnerability at higher age (2, 3). This condition is characterized by several clinical manifestations such as sarcopenia, dynapenia, fatigue, sedentary lifestyle, malnutrition, cognitive decline and disability in activities of daily life (4, 5). Frailty is a typically unstable condition, which can be exacerbated by a multiplicity of triggers such clinical (disease, trauma, etc) and psychosocial (life events) origin (4). The most widely accepted approach of physical frailty is the phenotype which describes frailty in 5 components: exhaustion, low grip strength, unintentional weight loss, low physical activity and slow walking (6). Mainly the first two components, exhaustion and low grip strength, will be the focus of this work.

Disability and frailty in older patients are closely related to sarcopenia (2, 7, 8) which is loss of muscle mass and strength that occurs with aging (9). Sarcopenia and frailty are strongly interrelated (2), and often assessed by maximal grip strength. Exhaustion in frailty is currently only assessed by self-reported questionnaires (5, 10), the inclusion of a physical test could contribute to a more objective evaluation. Bautmans et al. in a series of nine original studies (9, 11-19) has introduced, refined and validated a new assessment method for muscle fatigue resistance (FR) as a direct and objective outcome parameter of the exhaustion component of frailty in elderly persons. The test measures the time during which grip strength drops to 50% of its maximum during sustained contraction (12). This test is now internationally accepted and several researchers as well as clinicians are using it. The FR test has been validated for the Martin Vigorimeter (VM)(12). Since this device is gentler for weak or painful joints (20) and allows performing a dynamic contraction (the rubber bulb is compressible), it is highly suitable to assess sustained maximal contractions in elderly subjects. However, many researchers and clinicians are using the Jamar Dynamometer (JD), a device designed to measure static grip strength. Grip strength measures obtained by the VM have been shown to be well correlated with those obtained with the JD (21). Although, until nowadays, no data regarding the FR test measured with the JD are available, hence limiting the implementation of the FR test. Validation of the FR test with the JD would improve the implementation in daily practice. Besides, the measurement of exhaustion in the frailty syndrome can be improved by the inclusion of the physical FR test. It is also important to investigate if there are significant differences in the muscular endurance between the different devices.

In this work we studied the strength decay and simultaneous EMG during the FR test assessed by the VM and the JD. Thanks to the simultaneous EMG registration it was possible to investigate the co-activation of the extensor and flexor muscles.

In the first part of this thesis the major concepts such as frailty, sarcopenia and muscular fatigue are defined. Subsequently the research question and the main objectives of the study are elaborated, followed by the experimental part including methods and results sections. The final part is the discussion and the overall conclusions of the work.

2. Major concepts

2.1 Frailty

Aging-related dependency and disability is a huge concern (22). The literature reveals that frailty is a condition extremely related to dependency at higher age (1). Frailty is considered a geriatric syndrome of decreased reserve in multiple physiologic systems and reduced resistance to stressors, causing increased vulnerability for adverse health outcomes including falls, hospitalisation, institutionalization and mortality (2, 3, 23).

It is now known that aging is not synonymous of frailty (4), as stressed by Wou and Conroy "*Not all of the oldest old are frail, and not all frail people are aged"* (10). Considering that frailty can appear in one-quarter of the elderly people, without pre-existing multiple co morbidities or disabilities, it is relevant understand how frailty develops (7).

In spite of a distinct physiopathology, the underlying pathways leading to frailty are assumed to be part of a multidimensional entity comprising physical, psychological and sociological components, with a particular involvement of inflammatory processes, and changes in hormonal homeostasis and body composition (2). Frailty is not a synonym of aging neither of dependency, disability or co morbidities (10, 24).

Fried et al. defined physical frailty according to five criteria: weight loss, exhaustion, low physical activity, slow walking speed and weak grip strength (6). Subjects showing 3 or more criteria are considered as frail; presence of one or two criteria is defined as pre-frailty; negative on all criteria is defined as healthy (6). There are many other scales to assess frailty (25), for example the list of variables used by the Canadian Study of Health and Aging to construct the 70-item Frailty Index that analyses items together such as co morbidity, cognitive impairment and disability (26). Although most of it is hard to compare the measured outcome of these instruments with each other because of the differences in frailty instruments (25). Most of the instruments focus just on physical frailty (nutrition status and mobility), and only a few included items on three domains such physical, psychological and social domain (25, 27). Comparing these two approaches to frailty, both of them have demonstrated that adverse outcomes occurred more commonly among people who were frail (26). The physical component of frailty is the most studied until now (28). Despite the different criteria for diagnosis, the loss of muscle mass with aging is considered as a major cause of functional decline and disability (29), this means sarcopenia is the major component of frailty. Although they are not the same, there are an overlap range from 50% to 70% between this conditions (30).

2.2 Sarcopenia

Sarcopenia is an important change in body composition and function, it is described as a progressive and widespread decline in muscle mass, strength and physical performance in elderly people, which increase the risk for nursing home admissions and loss of independence, as well as an increase in weakness, falls and fractures (31). Low muscle mass is most often defined as a skeletal muscle mass index (muscle mass expressed by height² or as percentage of total body mass) between 1 and 2 (32, 33). Standard deviations (SD) below a young

reference group for class I sarcopenia (moderate) and lower than two SD for class II sarcopenia (severe) (32). It has been shown that sarcopenia is associated with functional impairment and disability and confirming that is a significant public health problem (34). The relevance of sarcopenia in the clinical decision making is underlined by the recommendation to include it in the comprehensive geriatric assessment (35). In 2010, the European Working Group on Sarcopenia in Older People (EWGSOP) proposed an operational definition for sarcopenia as well as a guide to standardize the evaluation of sarcopenia (36). Conceptually, sarcopenia is a term utilized to define the progressive and generalised loss of skeletal muscle mass and strength that increase the risk of adverse outcomes such as physical disability, poor quality of life and death (9, 31, 36). However, for clinical purposes, the EWGSOP proposed to include also the measurement of muscle strength (e.g. grip strength) and physical performance (e.g. walking speed) besides muscle mass assessment (8, 36). Despite the EWGSOP criteria, there is no conclusive definition of sarcopenia so far (37, 38).

The main adverse health consequences of sarcopenia are falls and loss of independency, increased health costs, reduced quality of life and increased mortality (28, 30, 31, 36, 37, 39, 40). Glucose regulation, hormone production, cellular communication and protein storage and turnover are also related impairments in physiological functions (8, 28, 41). With age, atrophy affects mostly type II fibres compared to type I (25–60% versus 0–25% reduced single fibre cross-sectional area (42). In general, the postural muscles show more type I fibres and the upper limbs more type II fibres (43).The muscle fibre atrophy is caused by a reduced rate of myofibrillar muscle protein synthesis and a higher catabolic activity at old age (42).

Sarcopenia is present in about 5 to 10 % of persons over 65 years of age although the prevalence varied strongly according to the criteria used and with the region (30). Sarcopenia represented an estimated cost of about $18.5 billion in the United States in 2000, representing 1.5% of total healthcare expenditures (34).

More research is necessary to understand the nature of this syndrome in order to improve medical therapy and avoid the adverse consequences of it, manly the interaction of anabolic hormones and exercise (9).

2.3 Muscle Fatigue

In this paragraph, muscle fatigue is briefly explained after a short introduction of the neurophysiology of the muscular system. The muscular system is constituted by different kinds of muscular tissue (skeletal, smooth and cardiac muscles). The capacity of movement and consequently the independency in activities of daily living are possible thanks to the muscles that contract (43). The skeletal muscle is responsible for physical movements, as is the only one that is able to contract voluntarily. The contraction is always triggered by a neuronal stimulus, releasing acetylcholine in the neuromuscular junction and activating the sarcolema (43).

These events can be measured via recoding the electrical activity of the muscle by electromyography (EMG, expressed in millivolts) (44). This measurement is possible as the cellular membranes (de)polarize inducing changes of electrical charges. The difference of

potential between the membrane of nervous cells and the muscular fibres is between -70 and -90 mV (43).

Fatigue is characterized as a decrease of the capacity to perform muscle work that usually follows a period of activity (45). Fatigue is a common feeling in humans, although it is experienced in different ways (43). Fatigue can occur in three potential places: the nervous system, the muscles or in the neuromuscular junction (43). The psychological fatigue is the most common type and finds its origin in the central nervous system (46). This fatigue and its duration depend on the mood state of the person (11, 46). Muscular fatigue can result from depletion of ATP which occurs in the muscle fibre (43, 45, 47). Synaptic fatigue occurs rarely, because is when the acetylcholine release might be insufficient to stimulate the muscles fibres (43).

A new assessment to evaluate muscle FR as a direct and objective outcome parameter of the exhaustion component of frailty in elderly persons has been proposed by Bautmans et al. (12). In order to assess the muscular endurance in hospitalized elderly people a FR test was developed for elderly people based on grip strength (12). The test measures the time during which grip strength drops to 50% of its maximum value during sustained maximal contraction (12). Emphasizing the VM device is highly suitable to assess sustained maximal contractions in elderly subjects (48), since it is gentler on weak or painful joints (20) and allows performing a dynamic contraction (the rubber bulb is compressible). Nevertheless the JD was designed to measure static grip strength and is being used frequently, although it is heavier that the VM (48-53). However they trigger different contractions, and had different until nowadays, no data regarding the FR test measured with the JD was available, thereby the implementation of the FR test is limited. The VM measures a isotonic contraction (the rubber bulb is compressible) and the JD measures a isometric contraction (the handle is not compressible) (48). Even though the grip strength had a high correlation between the two measurements (21), muscle fatigue might occur differently during sustained maximal grip effort (45).

In addition, a supplementary muscle endurance outcome, denominated as Grip Work, was developed thought the integration of maximal grip strength and FR in order to improve the interpretation of FR scores (16). This parameter represents the physiologic work delivered by the handgrip muscles during the FR test. Grip work is graphically represented by the area under the curve with grip strength in the vertical and time in the horizontal axis (11, 16). Besides age and gender, several other parameters can influence FR and grip work as measured with the VM, among which physical activity, self-perceived fatigue, body composition, functional capacity and inflammatory processes (11-19).

There are neurophysiologic change that were related to induce dynapenia (age-related muscle weakness (54)), such as the deficit in maximal voluntary muscle activation (MVMA) and increased antagonist muscle co-contraction (55). The MVMA as pointed by Arnold & Bautmans, "*The maximal voluntary muscle activation is reached when MU recruitment is complete and all recruited units are discharging at their maximal frequency*" (56). The magnitude of co activation during muscular voluntary contractions (MVCs) is typically assessed by expressing EMG activity

in the antagonist muscle as a percentage of its activity when acting as an agonist during a maximal contraction (56). Co-activation appears to be higher in elderly compared to younger adults during isometric contractions (55, 56).

3. Aim of the study

This thesis is part of a larger research project comparing the strength decay during the FR test obtained by the VM and the JD in adult subjects of different ages and clinical condition. This thesis is based on the first series of community-dwelling adults included in the project, with a specific focus on agonist and antagonist muscle (co-)activation during the FR test.

4. Methodology

4.1 Study design

This is a cross sectional (57), explorative study with a test-retest design (58). This study was the first results of a major project that is being developed.

4.2 Participants

Healthy community-dwelling adults were recruited via flyers and announcements in local media (journals, websites and local television) and/or through the students' network. For the young (aged 18-30 years) healthy reference group, preferentially students of Vrije Universiteit Brussel (VUB, Brussels, Belgium) and Stichting Opleiding Musculoskeletale Therapie (SOMT, Amersfoort, The Netherlands) were approached for participation.

In order to be eligible to participate in this study, the subjects had to meet all of the following inclusion criteria, respectively with the group that were include:

a) **Young, healthy subjects** aged 18-30 years (reference group): completely healthy, no medication use, no impairments interfering with muscle FR test, normal physical activity (i.e. at least 150 minutes/week at moderate intensity but no competitive sports measured with The Yale Physical Activity Survey (59)).
b) **Community-dwelling subjects** aged >30 years: living independently in the community, no functional disability of the dominant upper extremity (paresis/paralysis, tremor or recent surgery), normal cognitive functioning (Mini-Mental State Examination [MMSE] score >23/30(60)), living independently in the community.

The exclusion criteria were pregnant women and in group community-dwelling subjects people who had an acute or uncontrolled condition, chronic inflammatory pathology and/or central nervous disease (e.g. Parkinson's disease, Multiple Sclerosis, Cerebro-Vascular Accident).

The study protocol was approved by the ethical committees of the Universitair Ziekenhuis Brussel (University hospital of the Vrije Universiteit Brussel, Brussels, Belgium) and

Atrium-Orbis-Zuyd (Heerlen, The Netherlands). All participants gave their written informed consent.

4.3 Measurements

The data was collected between February and April 2015. FR and strength decay were assessed both by the MV and JD in a random order. The randomization was the technique used to create the initial equivalent between groups (58). Before the groups had the same characteristics with respect to the dependent variables and socio-demographic variables. This allows the groups to mach in such a way that the individual characteristics of participants are present in both groups. The technique used to decide on the participants group was heads or tails.

4.3.1 Surface electromyography

Some factors were report to interfere with the EMG data: influence of the subcutaneous tissue thickness, effect of varying inter-electrode distances, orientation relative to muscle fiber direction, position of electrodes relative to the innervations zone on amplitude values (61). In order to reduce these influences some procedures were taken carefully. First, the skin of the dominant forearm was prepared (44, 62, 63). The area of the muscle mid-belly was shaved and cleaned with 70% of ethyl alcohol (64). Two circular electrodes (4 cm diameter) were placed with an inter-electrode distance of 3,4 cm (61) on the muscle belly, located by palpation of the contraction of the muscle. The performance of contraction of each muscle was required by the following exercises:

- ✓ The *extensor digitorum brevis* muscle the subject was asked to move the middle finger up and down,
- ✓ The *flexor digitorum superficialis* muscle the subject was asked to squeeze the hand.
- ✓ The reference electrode was placed on the proximal part of the Ulna.

All raw sEMG signals were simultaneously sampled at 5000Hz (Butterworth 4^{th} order, band-pass 10-500Hz and notch filtered) and stored on a personal computer.

4.3.2 Fatigue Resistance

Tests were performed on the same day with at least one hour interval. FR scores of the first test were masked for assessor and participant during the second test. The FR test was performed by a modified digital manometer and Dynamometer G200 system, connected to a MPAQ universal amplifier (Maastricht Instruments) in order to appraise muscle fatigue curves. The modified VM and Dynamometer G200 had an identical rubber bulb and handle as respectively the original MV and JD (Figure 1 and 2), but were equipped with respectively a pressure and strength gauche that allow continuous registration of the strength decay during the FR test. The instrument setting of the Modified VM was characterized for large rubber bulb connected to a digital manometer and the values were recorded in kilopascal (KPa). In the other hand the values of G200 Dynamometer were recorded in Kilogram (Kg).

Data acquisition was at 5000Hz and notch-filtered. Only the dominant hand was tested.

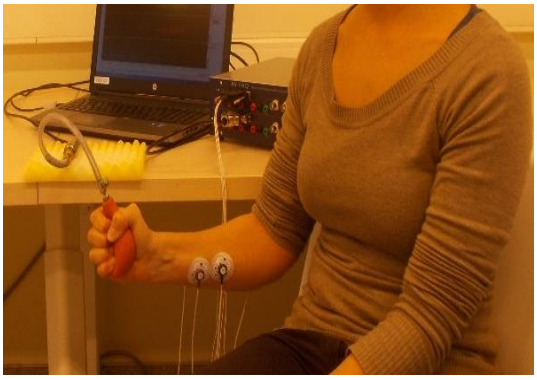


Figure 1: Modified VM

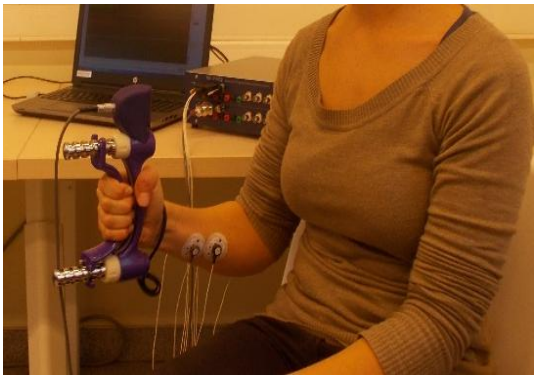


Figure 2: G200 Dynamometer

During the FR test the participants needs to take a standard position (12, 20, 21). Seated on a chair, the shoulder adducted and neutrally rotated, elbow flexed at 90°, forearm in neutral position and wrist in light extension (0 to 30°) (20, 65). No support of elbow allowed (e.g. no use of arm rests allowed). During the performance using the modified VM the subject grasps the large rubber bulb with the thumb round one side of the rubber bulb and the four fingers around the other side of the rubber bulb (Figure 1). The connecting tube to the rubber bulb is oriented upwards. While during the performance using the G200 dynamometer the subject grasps the handle of the dynamometer with the thumb round one side of the handle and the four fingers around the other side (Figure 2). The grip strength display is oriented upwards.

In order to obtain sEMG data of maximal finger extension (necessary in order to calculate the muscle activation level of the finger extensors during the FR-test) an isometric maximal finger extension test was performed. The subject was seated on a chair with the elbow, forearm and palmar part of the hand on a table; the fingers (2^{nd} – 5^{th}) were outside unsupported outside the table. The subject was asked to extend the fingers as high and as hard as possible; the investigator manually pushed the fingers towards flexion sufficiently hard to overcome the extension strength of the participant. This test was repeated three 3 attempts were performed.

The subject was asked to squeeze the large bulb of the modified VM / the handle of the G200 dynamometer as hard as possible. The highest of three attempts was noted as the maximal grip strength (in KPa / Kg).

The same position as for the grip strength test of the participant's hand and arm was adopted to perform the FR test. Participants were instructed to maintain the elbow in 90° flexion and were not allowed to see the readings on the manometer / dynamometer at any time during the procedure. The subject was instructed to squeeze again the large bulb of the modified VM/ the handle of the G200 dynamometer as hard as possible and to maintain this maximal effort as long as possible. The observer verifies that the starting strength corresponded to the maximal grip strength tested before and, if too low, encouraged the participant to squeeze as hard as possible. Standardized verbal encouragement ("Keep squeezing, don't let go") was given to the subject each time the pressure diminished. The test stopped when the grip strength dropped below 50% of its maximum and the subject could not increase the strength despite verbal encouragement. The time (in seconds) during which grip strength dropped to 75% and 50% of

its maximum was recorded as FR75% and FR50% respectively. The strength output (and sEMG) were synchronously and continuously recorded during the test and stored on a local computer until post-processing.

Before every single test performed was essential calibrate the device correctly, this procedure was done (44, 66).

4.5 Data Processing

From the maximal isometric finger extension test sEMG data of the maximal finger extension was obtained. In figure 3, the 3 attempts can be differentiated. The red curve corresponds with the muscle activation of the muscle extensor, the yellow one corresponds with the muscle co activation of the flexors (Figure 3). In the curve corresponding with extensor activation, the goal was to find the maximum level of muscle activity, which was described as maximal extension in mV. Once it was established in which attempt the maximal muscle activity was reached during the sEMG registration, this specific attempt was analyzed for a two second plateau (constant extensor activity). The root mean square (RMS) of the extensors and flexors muscle activation during the selected two seconds was gathered respectively from the red and yellow curve and named maximal extension RMS extension and maximal extension RMS flexion.

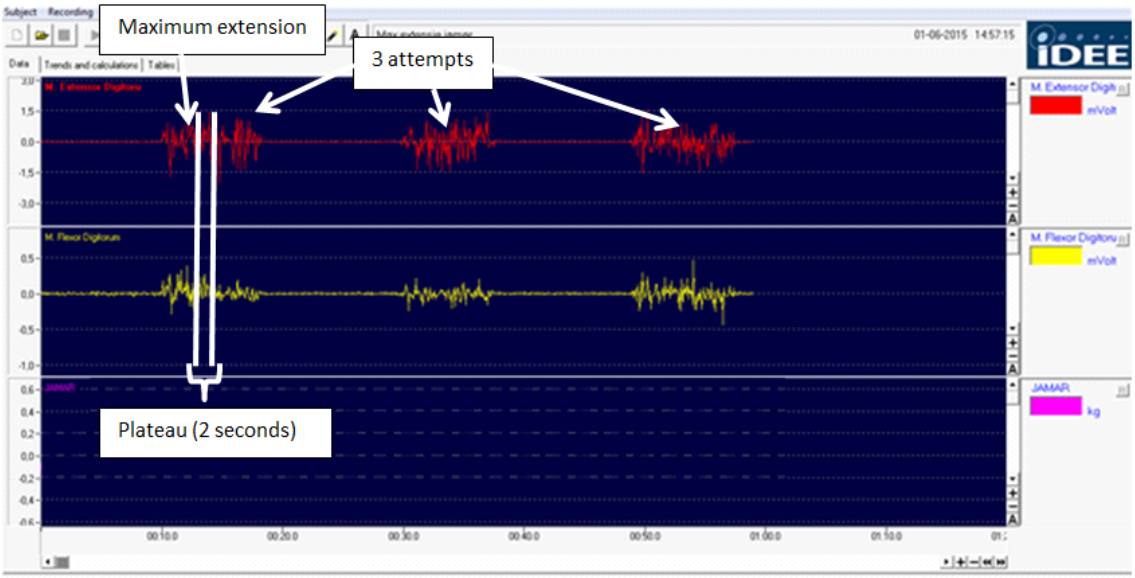


Figure 3: Example of data obtained from the maximal finger extension

During the maximal grip strength test the muscle activation of the flexors (yellow curve) and the extensors (red curve) of the forearm were simultaneous registered (Figure 4). After which the maximum level of muscle activation was searched in the curve of the flexor activation, this was described as maximal flexion in mV. Once identified which attempt contained the maximal level of muscle activity, a plateau of two seconds (constant flexor activity) was sought in that specific EMG registration. The RMS of the extensors and flexors muscle activation and the strength during the selected two seconds was gathered respectively from the red, yellow

and purple curve and named maximal flexion RMS extension, maximal flexion RMS flexion and maximal flexion RMS force.

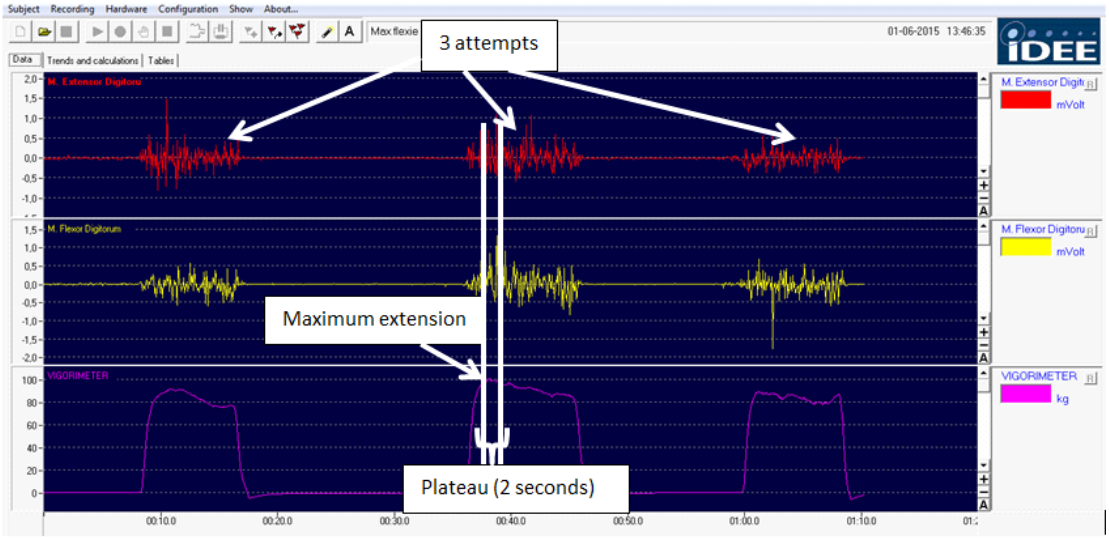


Figure 4: Example of data obtained from the maximum flexion

From the curve representing strength in the FR test (purple curve) different values could be determined: maximal strength (F=100%), 75% of maximal strength (F=75%) and 50% of maximal strength (F=50%), as well as the timeframe in which these values were achieved (respectively T100%, T75% and T50%).

Likewise, the RMS was calculated over a two second period for the extensors (FR RMS T_x extension) and flexor muscle activity (FR RMS T_x flexion) as well as the strength registration (FR RMS T_x force) during the FR test in the three moments (T100%, T75% and T50%). This two seconds period was calculated for maximal strength (T100%) by selecting exactly 1 second before and after of reaching max strength (Figure 5). The moment T75 was achieved, two consecutive seconds were searched where muscle strength was equal or less than the result of subtract two kPa/ 100 gram (respectively FR test measured via VM and JD) to the 75% of max. muscle strength. The two seconds period just before the subject reached 50% of max. strength was selected and the RMS was also calculated for muscle activity of the extensors, flexors and strength during that selected period.

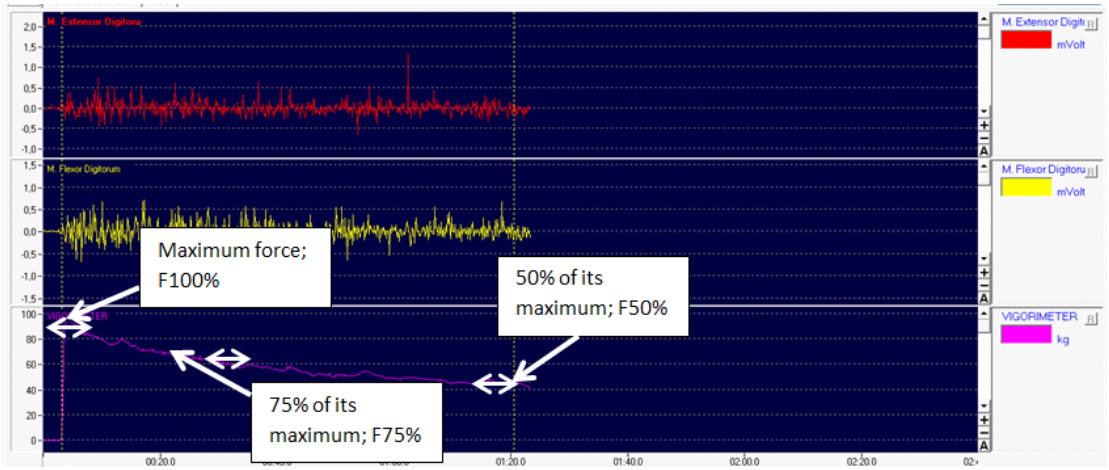


Figure 5: Example of data obtained from the FR test

Due to the data gathered from the maximal finger extension, maximal grip strength and FR test, we were able to determine the antagonistic co activation and agonistic activation for the three periods approached during the FR test.

- Antagonistic co activation

Antagonistic co activation T_{100} = FR RMS T_{100} extension / maximal extension * 100
Antagonistic co activation T_{75} = FR RMS T_{75} extension / maximal extension * 100
Antagonistic co activation T_{50} = FR RMS T_{50} extension / maximal extension * 100

- Agonistic activation

Agonistic activation T_{100} = FR RMS T_{100} Flexion / FR RMS T_{100} flexion
Agonistic activation T_{50} = FR RMS T_{75} Flexion / FR RMS T_{100} flexion
Agonistic activation T_{50} = FR RMS T_{50} Flexion / FR RMS T_{100} flexion

Subsequently the difference between both devices in muscle (co) activation during the FR test was calculated for the time points T100%, T75% and T50%:

- Delta antagonistic co activation

Delta antagonistic co activation T_{100} = antagonistic co activation T_{100} (VM) - antagonistic co activation T_{100} (JD)
Delta antagonistic co activation T_{75} = antagonistic co activation T_{75} (VM) - antagonistic co activation T_{75} (JD)
Delta antagonistic co activation T_{50} = antagonistic co activation T_{50} (VM) - antagonistic co activation T_{50} (JD)

- Delta agonistic activation

Delta agonistic activation T_{100} = activation flexion T_{100} (VM) - activation flexion T_{100} (JD)
Delta agonistic activation T_{75} = activation flexion T_{75} (VM) - activation flexion T_{75} (JD)
Delta agonistic activation T_{50} = activation flexion T_{50} (VM) - activation flexion T_{50} (JD)

- Delta fatigue resistance

Delta FR_{100} = FR_{100} (VM) - FR_{100} (JD)
Delta FR_{75} = FR_{75} (VM) - FR_{75} (JD)
Delta FR_{50} = FR_{50} (VM) - FR_{50} (JD)

4.6 Statistical analysis

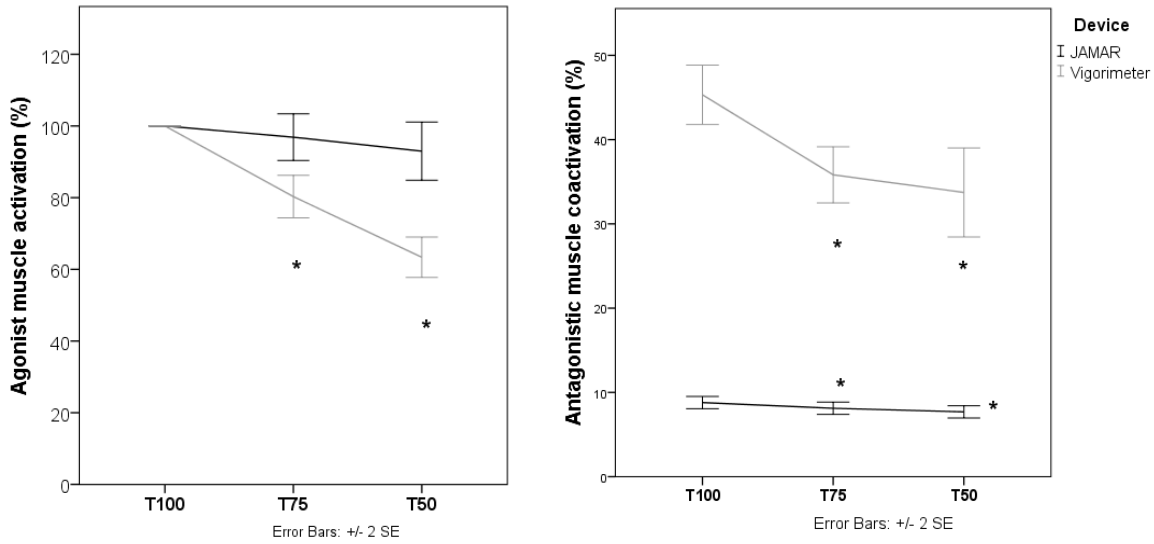
For all variables, descriptive statistics were calculated and distribution normality was verified using the Kolmogorov-Smimov Goodness of Fit test (58). Differences between genders and devices were analyzed using respectively Independent Samples t-test and the Paired Samples t-test. The Pearson's correlation coefficient was calculated to determine the relationship between FR and agonistic and antagonistic muscle activation. Where relevant, partial correlation coefficients were computed, controlling for age and gender. Changes in muscle activation during the FR-test were analyzed using repeated-measures Analysis of Variance (ANOVA) with device (VM & JD) as between-subject factor and Bonferroni post-hoc testing. All statistics were performed using the IBM SPSS statistics version 22.0.0.2. Significance was set a priori at $p<0.05$.

5. Results

The sample was constituted by 56 community-dwelling participants (30 female and 26 male). However two of them were not compliant to the test instructions and thus excluded for the data analyses.

As shown in table 1, female participants were significantly smaller than men. Female showed weaker hand grip strength with both devices than male. Compared to men, FR75 measured with JD in women was shorter ($p<0.05$); for VM this difference was at the limit of significance ($p=0.051$). This difference between the genders disappeared for FR50. The other characteristics, like body weight or BMI did not reveal significant gender differences.

Fatigue resistance (FR75 and FR50) was significantly better when measured with VM compared to JD. At all phases of the FR-test (T100%, T75% and T50%) the antagonist muscle co-activation was significantly higher for VM compared to JD (all $p<0.05$, see table 1 & Figure 6). In contrast, the agonist muscle activation level was significantly higher in JD compared to VM at T75% and T50% ($p<0.05$, see table 1 & figure 6). When performing the FR-test with VM, both the agonist muscle activation and antagonist muscle co-activation decreased significantly ($p<0.05$), whereas when using the JD, only a significant decrease in the antagonist muscle co-activation was observed (see figure 6).



*****Significant difference between time points (T100% and T75% and T100% and T50%)

Figure 6: Percentage of muscle activation and co activation during the FR test

Table 1: Participants characteristics stratified by gender (data expressed as mean ± SD[1])

Parameter	Female	Male	Total
Gender (n)	N=29	N=25	N=54
Age (y)	38.83 ± 17.16	41.32 ± 19.39	39.98 ± 18.09
18-40	24.75 ± 1.18 (N=16)	28.19 ± 1.70 (N=16)	26.47 ± 6.02 (N=32)
41-60	52.40 ± 1.34 (N=10)	54.33 ± 3.84 (N=3)	52.85 ± 4.63 (N=13)
+60	68.67 ± 3.28 (N=3)	69.83 ± 1.76 (N=6)	69.44 ± 4.48 (N=9)
Height (kg)*	169.17 ± 6.29	181.29 ± 6.08	174.66 ± 8.65
Weight (kg)	75.62 ± 20.09	84.59 ± 11.47	79.76 ± 17.13
BMI (kg/m2)	26.88 ± 6.82	26.46 ± 4.57	26.69 ± 5.84
F100_JD (Kg) *	31.11 ± 5.78	42.41 ± 8.24	36.35 ± 8.98
F100_VM (KPa) *	71.14 ± 19.31	93.23 ± 20.06	81.36 ± 22.42
FR75 †			
JD (sec) *	6.47 ± 3.74	9.38 ± 4.99	7.81 ± 4.56
VM (sec) *	16.23 ± 9.51	21.57 ± 10.11	18.70 ± 10.07
FR50 †			
JD (sec)	33.91 ± 13.96	30.74 ± 15.16	32.44 ± 14.48
VM (sec)	62.61± 29.23	60.77 ± 21.99	61.76 ± 25.91
Antagonist Muscle Co-activation T100% †			
JD	8.65 ± 2.71	8.96 ± 2.72	8.79 ± 2.70
VM	45.64 ± 12.55	44.94 ± 13.67	45.31 ± 12.96
Antagonist Muscle Co-activation T75% †			
JD	7.90 ± 2.24	8.37 ± 3.13	8.12 ± 2.68
VM	36.38 ± 11.86	35.18 ± 12.87	35.82 ± 12.23
Antagonist Muscle Co-activation T50% †			
JD	7.45 ± 2.55	7.97 ± 2.88	7.69 ± 2.69
VM	37.88 ± 24.14	28.92 ± 10.40	33.73 ± 19.42
Agonist muscle Activity T75% †			
JD	95.39 ± 21.12	98.59 ± 27.23	96.87 ± 23.96
VM	84.21 ± 24.67	75.77 ± 17.32	80.30 ± 21.80
Agonist muscle Activity T50% †			
JD	94.75 ± 29.22	90.90 ± 30.90	92.97 ± 29.79
VM	66.44 ± 24.14	59.82 ± 15.33	63.37 ± 20.63
Antagonist Muscle Co-activation T100% VM-JD	36.98 ± 11.08	35.98 ± 12.20	36.52 ± 11.51
Antagonist Muscle Co-activation T75% VM-JD	28.48 ± 10.61	26.81 ± 10.78	27.71 ± 10.62
Antagonist Muscle Co-activation T50% VM-JD*	30.43 ± 23.98	20.95 ± 9.39	26.04 ± 19.14
Agonist muscle Activity T75% VM-JD	-11.18 ± 29.51	-22.82 ± 27.68	-16.57 ± 29.01
Agonist muscle Activity T50% VM-JD	-28.31 ± 34.54	-31.08 ± 33.43	-29.59 ± 33.74
Δ^2 FR 75%	9.76 ± 8.95	12.20 ± 10.17	10.89 ± 9.52
Δ FR 50%	28.70 ± 527.06	30.03 ± 26.78	29.32 ± 26.69

*Significant difference between Male and Female ($p<0.05$)

†Significant difference between VM and JD ($p<0.05$)

[1] SD- Standard deviation

[2] Δ- Delta

As shown in table 2, a significant correlation (controlled for age and gender) was found between DeltaFR75 and delta antagonist muscle co activation T100% (r=.296, p<0.05) as well as between DeltaFR75 and delta antagonist muscle co activation at T75% (r=.276, p<0.05).

Table 2: Correlation between the muscles activity and the time to fatigue during the FR test

	Delta Antagonist Muscle Co-activation T100%	Delta Antagonist Muscle Co-activation T75%	Delta Antagonist Muscle Co-activation T50%	Delta Agonist muscle Activity T75%	Delta Agonist muscle Activity T50%
DeltaFR75	.296*	.276*	.200	-.029	.124
DeltaFR50	.196	.177	-.057	-.051	.155

Data represent Partial correlation coefficients controlled for age and gender *p<0.05.

In table 3 the results are presented stratified by age and gender. The younger female and male showed significantly higher maximal grip strength for both devices compared to the older ones. The strongest group was the 18-40 year old, but this group had also the lowest FR values. This age effect in fatigability (FR50) was only significant in females. The group of 60+ showed significantly lower FR than group 18-40 when using the VM (18-40: 52.36 ± 19.26 vs. 60+: 98.15 ± 58.75). But when using the JD device, FR was higher in the 40-60 age group (18-40: 28.31 ± 12.30 vs. 40-60: 43.79 ± 13.40).

In the male, the 18-40 group were taller and showed the strongest grip strength, whereas the group +61 was the weakest.

No significant differences were found for muscle (co)-activation muscular.

Table 3: **Participants characteristics by gender and age (expressed as mean ± SD)**

Female	**Age group**		
	18-40 years	**41-60 years**	**60+ years**
	N=16	N=10	N=3
Height (kg) $	171.50 ± 6.28 †	168.30 ± 4.08 #	159.67 ± 0.58
Weight (kg)	71.42 ± 17.64	85.78 ± 24.41	67.53 ± 5.22
BMI (kg/m2)	24.83 ± 5.66	30.27 ± 8.37	26.53 ± 2.05
F100			
JD (Kg) $	32.31 ± 4.15 *	31.55 ± 7.01 #	23.30 ± 3.69
VM (KPa) $	77.18 ± 12.50 †	68.02 ± 24.29	46.09 ± 6.91
FR75			
JD (sec)	6.57 ± 3.37	7.06 ± 4.63	3.92 ± 1.77
VM (sec)	14.97 ± 7.52	17.84 ± 10.91	17.51 ± 16.72
FR50			
JD (sec) $	28.31 ± 12.30 *	43.79 ± 13.40	30.84 ± 5.70
VM (sec) $	52.36 ± 19.26 †	68.36 ± 25.05	98.15 ± 58.75
Antagonist Muscle Co-activation T100%			
JD	8.10 ± 2.81	9.54 ± 2.63	8.64 ± 2.51
VM	43.28 ± 13.30	46.60 ± 10.97	55.01 ± 12.46
Antagonist Muscle Co-activation T75%			
JD	7.79 ± 2.24	8.15 ± 2.56	7.65 ± 1.64
VM	35.25 ± 10.76	36.51 ± 13.83	41.96 ± 13.51
Antagonist Muscle Co-activation T50%			
JD	8.06 ± 2.87	6.57 ± 1.88	7.12 ± 2.55
VM	40.72 ± 30.38	33.96 ± 15.25	35.81 ± 6.19
Agonist muscle Activity T75%			
JD	101.25 ± 24.88	90.59 ± 13.11	80.19 ± 9.52
VM	88.20 ± 28.33	80.64 ± 15.74	74.89 ± 32.65
Agonist muscle Activity T50%			
JD	98.94 ± 26.32	96.54 ± 34.26	66.43 ± 10.90
VM	72.74 ± 25.22	59.80 ± 23.59	54.97 ± 12.09
Δ FR 75%	8.40 ± 6.48	10.78 ± 9.77	13.60 ± 18.30
Δ FR 50% $	24.05 ± 14.52 †	24.57 ± 21.37 #	67.31 ± 64.19

Male	18-40 years	41-60 years	60+ years
	N=16	N=3	N=5
Height (kg)$	182.88 ± 5.33 †	182.67 ± 6.81	175.40 ± 5.32
Weight (kg)	83.54 ± 12.15	93.33 ± 7.57	82.68 ± 10.40
BMI (kg/m2)	25.14 ± 3.91	27.97 ± 4.10	29.22 ± 5.62
F100			
JD (Kg)	44.08 ± 8.00	43.77 ± 8.54	37.31 ± 7.95
VM (KPa) $	101.47 ± 16.90 †	95.30 ± 8.79	70.22 ± 13.77
FR75			
JD (sec)	9.25 ± 4.82	6.37 ± 3.86	11.23 ± 5.86
VM (sec)	23.45 ± 11.33	17.95 ± 10.63	18.39 ± 5.36
FR50			
JD (sec)	27.47 ± 12.01	32.59 ± 26.83	38.55 ± 16.54
VM (sec)	57.85 ± 15.68	63.77 ± 28.68	67.07 ± 34.27
Antagonist Muscle Co-activation T100%			
JD	8.57 ± 2.32	8.47 ± 2.32	10.24 ± 3.93
VM	41.43 ± 12.49	43.24 ± 10.48	55.14 ± 14.77
Antagonist Muscle Co-activation T75%			
JD	8.56 ± 3.19	6.78 ± 1.30	8.64 ± 3.77
VM	33.43 ± 11.09	31.19 ± 6.07	41.83 ± 18.39
Antagonist Muscle Co-activation T50%			
JD	8.08 ± 2.74	7.63 ± 1.87	7.86 ± 3.96
VM	27.49 ± 9.72	26.61 ± 8.20	33.90 ± 13.00
Agonist muscle Activity T75%			
JD	104.75 ± 30.41	91.06 ± 20.76	85.93 ± 16.24
VM	75.60 ± 12.88	79.12 ± 8.12	74.54 ± 30.12
Agonist muscle Activity T50%			
JD	95.71 ± 34.41	88.06 ± 31.00	79.48 ± 20.31
VM	60.89 ± 16.76	61.89 ± 13.00	55.93 ± 13.91
Δ FR 75%	14.20 ± 10.50	11.58 ± 7.22	7.17 ± 10.04
Δ FR 50%	30.39 ± 15.87	31.18 ± 47.39	28.52 ± 42.25

$ Significant difference between age group
* Significant difference between age group 18-40 and 41-60
†Significant difference between age group 18-40 and 61+
#Significant difference between age group 40-60 and 61+
The Bonferroni post-hoc testing was used to compare the variables between age groups

6. Discussion

The first aim of this study was to validate the FR test when performing with JD, comparing the muscle fatigue outcomes obtained by the VM and the JD in dwelling community subjects of different ages. The second aim was to study the co-activation of the arm extensors and flexors during the FR test.

Even though the reliability of both JD and the VM has been evaluated in different populations (49, 50, 52), to our knowledge, these two types of instruments have never been compared measuring the FR test. Most studies of muscle function of elderly adults have focused on strength (20, 48, 51), thereby overlooking muscle fatigue as a potentially important link to normal activities of daily living requiring sub maximal sustained activity rather than maximal efforts (67, 68).

This study was in agreement with the previous results that the men are stronger than women (21, 48, 51). Since this thesis describes the first subjects included in a still ongoing research project, the sample size was not equally distributed among the age-subgroups, thus data must be interpreted with caution. As expected, elderly people showed less grip strength than younger ones (49, 53, 69).

Although a very high correlation between VM and JD has been described concerning grip strength (21), this was not confirmed for muscle FR. Emphasizing that muscle fatigue is a distinct parameter of muscle strength, as happen in knee extensors and flexor muscles (68).

The sample was large enough to demonstrate a significant difference in FR between the two devices. FR50 was in average 29 seconds better when performed using VM than the JD. This difference can be related to the type of contraction, which influences the muscle fatigue(70).

During the FR-test, strength dropped more rapidly to 75% of its maximum in female compared to male, but for FR50 the gender effect disappeared. The gender differences in muscle fatigability are still controversial and depend on specific muscle groups (71).

In all age groups we found a significant difference for FR between the devices. However, on both devices FR increased with age. Although, there was an exception for JD, where the middle-age group showed better FR compared to the younger and older ones. This can be due to the unbalanced proportions in age subgroups, effects of motivation or the feeling of pain (72). In addition age has previously been shown to be a predictor of fatigability, as was demonstrated in human adductor pollicis muscle during contractions of short duration and intermittent exercise (73).

The sEMG data revealed significant differences in muscle (co)activation during the FR test when comparing VM to JD (74). The antagonist co-activation was more pronounced when using the VM, whereas the agonist activation was greater when using the JD. This difference might be related to differences in the position of the wrist during the FR test (65), although this was very similar for both devices. On the other hand, the greater antagonist co activation when using the VM can positively impact the FR since antagonist co-activation is related to a better stabilization of the joint (55). Besides, previous studies showed that dynamic contractions (the rubber bulb of the VM is compressible and thus movement of the fingers is possible) were associated with greater FR compared to isometric ones (the handle of the JD is rigid) (70). Our data suggest that the FR-test when using the VM induces a more prominent muscle exhaustion than when using the JD. However, it remains unclear why grip strength declines so rapidly when using the JD, since agonist muscle activation decreased much less than when using the VM. Interestingly, the the difference in antagonist muscle co-activation at T50% (VM value - JD value) was higher in female. This could be related with the greater FR in women (71), but more investigation is required to confirm this relationship.

6.1 Limitations and future perspectives

In this study there are some limitations. First, the results regarding age-differences must be interpreted carefully since the study population was not equally distributed over the age-groups. However, this are the first results of a bigger ongoing project, and these first analyses must be confirmed when a larger group will be included.

In addition, the sample did not include disable people. Therefore, no conclusions can be drawn with regard to the comparability of the devices when used in people with impairments. This will be explored in the future project.

7. Conclusion

Fatigue resistance was significantly better when measured with VM compared to JD. At all phases of the FR-test (T100%, T75% and T50%) the antagonist muscle co-activation was significantly higher for VM compared to JD. In contrast, the agonist muscle activation level was significantly higher in JD compared to VM at T75% and T50%. When performing the FR-test with VM, both the agonist muscle activation and antagonist muscle co-activation decreased significantly ($p<0.05$), whereas when using the JD, only a significant decrease in the antagonist muscle co-activation was observed. Our results suggest that the FR-test when using the VM induces a more prominent muscle exhaustion than when using the JD, which makes the VM more suitable for measuring muscle FR. However, these findings must be confirmed in a larger study population.

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