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ORIGINAL PAPER

The use of acoustic myography to assess changes in muscle control with ageing in healthy subjects ranging 20 to 79 years

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Abstract
This study has used acoustic myography as a technique to assess not only the number of active fibres and their firing frequency, but also the efficiency with which they are recruited, to re-examine age-related changes in movement. It is known that ageing results in less precise and controlled muscle movements, changes that also occur with some neurological diseases. The aim of this study was therefore to look at the control with which two muscles, an extensor and a flexor, are activated and determine how, as well as which, changes occur with increasing age. In the upper limb it appears that the flexor declines later than the extensor muscle (m.Biceps vs. m.Triceps). This study lends support to the published evidence that proprioception and postural stability are regulated to some extent by muscle spindles and that this process is age-related. The changes are identifiable in the acoustic myography parameters (E-score and ST-score) and are observed in a muscle-specific manner.

Keywords Proprioception · Sarcopenia · Poor balance · Muscle weakness

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Introduction

With ageing it is well known that proprioception is impaired, such that the accuracy of muscle function/coordination becomes affected. This will in turn disturb overall balance to the extent that injury is a real risk (Ghai et al. 2017). Results from older adults also indicate a decline in muscle proprioception, this change is found to coincide with structural changes in the brain, the consequences of which is are a reduction in fine motor control (Landelle et al. 2021). Movement is monitored and regulated by three systems of sensors. One is the Muscle Spindle, which is located in between muscle fibres and serves to monitor changes in muscle length and the speed with which these occurs. Secondly, there is the Golgi tendon Organ (GTO) which is placed between the collagen fibres that make up the tendon, and it serves to monitor the tension transfer from muscle to bone (Zampieri and de Nooij 2021; Cronin et al. 2011). Of interest is the finding that a decrease in the response amplitude of the Hoffmann and muscle stretch reflexes following a contraction of a stretched muscle is not the result of activating Golgi tendon organs but could be a pre-synaptic inhibition of the spindle sensory signal (Chalmers 2004). For both muscle spindles and Golgi tendon organ pathways, rapid adaptation to successive contractions has been reported (Hutton and Atwater 1992). The signals from muscle spindles appear though to be set at a higher threshold and will not easily desensitize, while those from the Golgi tendon organ appear to be desensitized over a shorter period of time (Hutton and Atwater 1992). A third set of sensors is the Pacinian Corpuscles (PC). These are located in joint capsules and serve to detect the precise position of every joint in the body (Mahato et al. 2023).

With increasing age, the GTO has been shown to decrease in number, as have the Pacinian corpuscles (Morisawa

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1998; Gescheider et al. 1994; Cerimele et al. 1990). Studies dealing specifically with the implication of this change have not been forthcoming. Regarding the PC, morphometric analysis suggests structural changes resulting in an increase in size as well as capsule thickness with increasing age (Mahato et al. 2023). In contrast Garcia-Piqueras and colleagues question differences in the PC between young and old human subjects, although some differences were noted (Garcia-Piqueras et al. 2019).

Luu and colleagues found that with administered curare, which entered and left the muscle with a delay in its paralyzing effect, it was observed that there was a false lower assessment of the actual weight being lifted during the time when curare continued to affect the intrafusal fibres of the muscle spindle. The authors concluded that when paralysis of intrafusal fibres is greater than that of the extrafusal fibres, muscle spindle receptors inaccurately assess the weight being lifted by an active muscle (Luu et al. 2011). This strongly indicates that muscle function is not solely driven by the motor cortex but is regulated in combination with local signals from muscle spindle receptors as well as the central processes within the brain (Monjo and Allen 2023).

In the present paper we wish to focus on the possible connection between muscle spindles and muscle function with increasing age based on acoustic myography data combined with already published data.

Subjects and muscles

The raw data for this study was originally collected and published in Bartels et al. (2020), and data for the oldest group was from taken from the Healthy Control data in Celicanin et al. (2023). In total, this provided data from healthy subjects aged between 20 and 79 years. Each decade comprised 10 subjects and the recordings from the m.Triceps and m.Biceps were used.

Both studies included followed the guidelines set by the Helsinki Declaration 2013 (http://www.wma.net/en/30publications/10policies/b3/), were approved by the Capital Region of Denmark's Ethics Committee and were registered with the Danish Data Protection Agency. Details concerning these subjects can be found in the published papers (Bartels et al. 2020; Celicanin et al. 2023).

Methods

Acoustic myography (AMG) is a non-invasive technique that measures the contractile signal in terms of it's amplitude (S-score; spatial summation) and frequency (T-score; temporal summation), as well as the degree of coordination with which a contraction occurs (E-score) (Harrison 2018; Bartels et al.2020). These three parameters are referred to as a combined ESTi™ score but can also be used independently or as a ST-score. The ST-score is a mean of the AMG S- and T-scores, and it correlates closely with muscle force (Claudel et al. 2018).

AMG as a technique is characterized by measuring the actual contraction by the three parameters that combine to produce it. This is different from surface electromyography (sEMG) which is purely a measurement of the electrical signal that gives rise to contraction. Thus, AMG provides the opportunity to investigate any possible age-related effects on the part of regulation of contraction which resides in the muscle fibre bundles themselves. Both included studies measured muscle activity using AMG (Bartels et al. 2020; Celicanin et al. 2023).

The present study focuses on the correlation between age-related changes in the efficiency, the E-score, with which the two muscles are used and on changes in the ST -score.

Results

The figure above indicates that m.Triceps (•) is relatively insensitive to a decline in the E-score (loss of proprioception) with age. In other words, there is no change in healthy subjects in the recruitment of fibres nor in the motor unit firing frequency up to the age of 60–69. For m.biceps (•), however, it would seem that this muscle is more sensitive to the aging decline in proprioception, such that when the E-score decreases, this muscle recruits more fibres and increases the motor unit firing rate.

Discussion

In this study we focus mostly on the level of efficiency/coordination of muscle use, as measured as the AMG E-score, in relation to increasing age in two functionally different muscles in healthy subjects. Our data has revealed an interesting muscle-specific difference in the E-score when correlated with changes in the ST-score. The ST-score has previously been shown to correlate with voluntary muscle force in the muscle Palmaris longus which although a flexor, plays a minor role in flexion of the wrist (Claudel et al. 2018). Ageing is known to result in a loss of muscle mass, so called sarcopenia (Sayer et al. 2024), which reduces the total force muscles are capable of, and thereby may affect joint stability as well as proprioception.

This study is limited to the fact that only ten subjects in each age group were measured using acoustic myography, and that measurements were restricted to just the upper arm flexor/extensor muscles (m. Biceps/m.Triceps).

The ST-score correlates closely with sub-maximal muscle force, which is more frequently used in everyday tasks. This means that whilst maximal force for any given muscle may become reduced with increasing age, the way remaining muscle fibres are used to generate force stays more or less constant (see Claudel et al. 2018). It should be noted that the study by Claudel et al. recruited subjects up to a maximum age of 53 for men and 68 for women (Claudel et al. 2018). Hold together with the data on muscle strength with aging by Sayer and colleagues, it is seen that the mean grip strength is only slightly affected in men by the age of 53 and women at the age of 68 in Europe (Sayer et al. 2024). What happens with the ST-score in the older age group is therefore not studied by Claudel et al. However, anticipatory postural adjustments (APA) are found to be very precise in the young individuals, but from around the age of 65, it becomes less accurate. This change suggests that with age the sensitivity of proprioception becomes impaired. The result of this is an elevated risk of postural instability (Kimijanova et al. 2021).

The question in this study is how proprioception may change with age, and when it becomes a problem concerning balance and movement. The efficiency/coordination of muscle use, the E-score, is a good measure of changes in proprioception with increasing age. Here we have looked at a wider age group of subjects (20–79 years) to study the control with which the extensor (m.Triceps) and the antagonistic flexor (m.Biceps) are activated and to determine any changes occurring with increasing age. What has become evident is that the two muscles (extensor and flexor) are

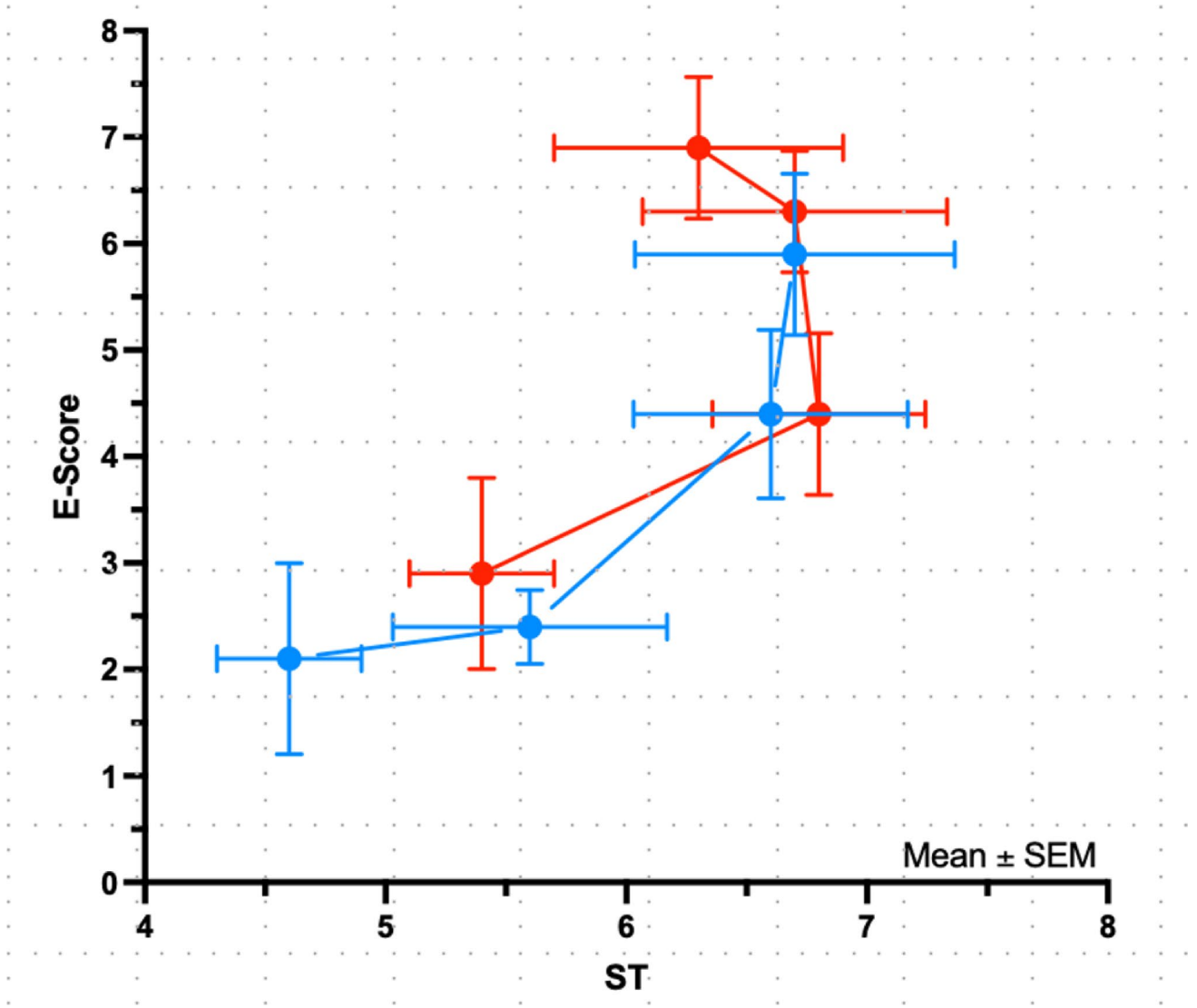

Fig. 1 Correlation between the E-score (Y-axis) and the ST-score (X-axis) for subjects aged 20–79 years, and for both m.Triceps (•; extensor) and m.Biceps (•; flexor). Age ranges for the four groups presented are 20–29, 40–49, 60–69 and 70–79 years for the mean values starting at the top of the figure and running vertically down when measured alongside the E-score. Values are the mean ± SEM ($n = 10$)

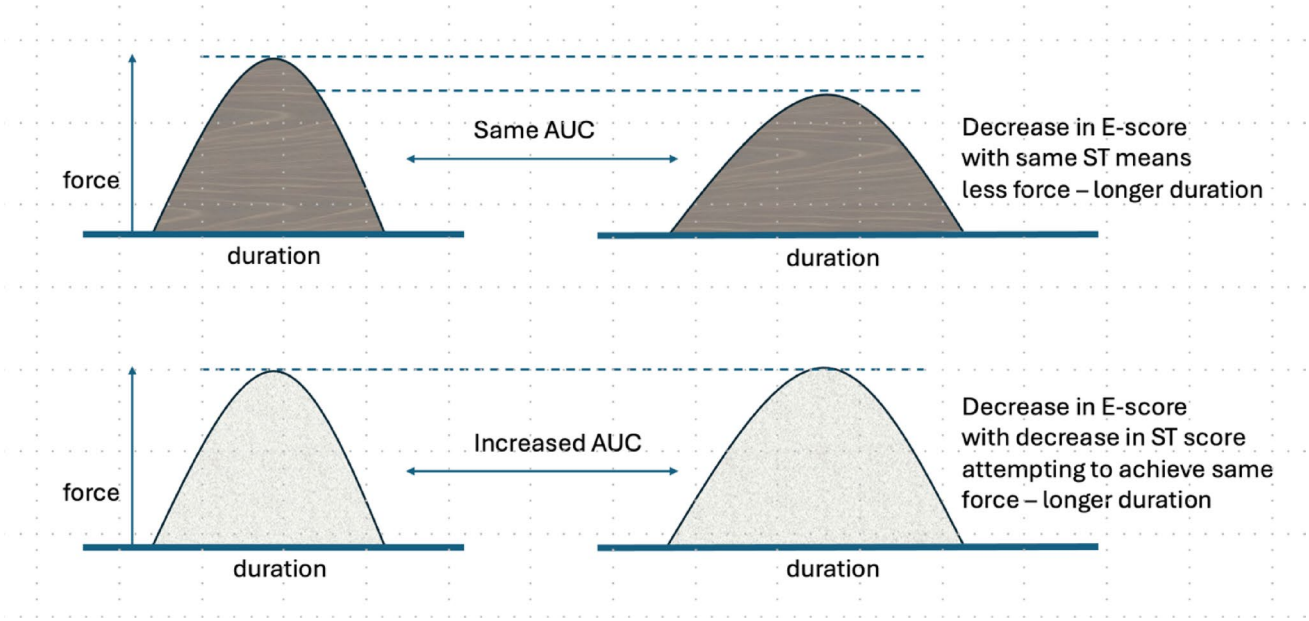

Fig. 2 Force – duration curves showing the situation where a stable E-score cannot be maintained any longer by changing the ST-score (Upper Panel - right). The left side represents a young subject where this is not the case. In the Lower Panel the situation represents the case where the coordination has become less efficient with increasing age (decreasing E-score), but the muscle has increased the number of active fibres and/or the firing rate (decrease in ST-score). AUC denotes the area under the curve

affected by increasing age in slightly different ways. In the extensor (m.Triceps) very little change in ST occurred up to the age of 69, although the E-score decreased from approx. 7.0 to 4.5. In contrast, the flexor (m.Biceps) in the 60–69 age group had already decreased in ST from approx. 6.5 to 5.5, and the E-score had decreased from around 6.0 to 2.5. Of further interest was the 70–79 age group in which the E-score was found to be between 3.0 and 2.0 for both extensor and flexor, yet, in terms of the ST-score the two muscles differed: (m.Triceps extensor = 5.5 versus m.Biceps flexor = 4.5)

In terms of recruitment of fibres and force production, timing becomes important. A muscle can generate force by recruiting only a few fibres, yet firing them almost simultaneously, or the same amount of force can be generated by firing more fibres but in a less coordinated way (see Fig. 2).

Looking at the force duration curves, Fig. 2, and comparing them to the results in Fig. 1, when a muscle exhibits a decrease in efficiency/coordination (a fall in E-score) with increasing age, this change in efficiency/coordination may be compensated by recruiting more fibres and/or firing them at a faster rate, which would be seen as a decrease in the ST-score. Failing this, a muscle would become weaker with increasing age and poorer coordination, as a combined result of its inability to maintain a stable E-score as well as adapt the ST-score which has been shown to closely correlate with muscle force (Claudel et al. 2018; see Fig. 2).

It has been hypothesized that a copy of central motor commands (referred to by Christensen et al. (2007) as an efference copy), exists in the prefrontal motor cortical region of the brain or a supplementary motor area. An efference copy is a neural mechanism where a copy of a motor command is sent to sensory areas of the brain before the actual movement occurs. Such a mechanism allows the brain to predict and compensate for the sensory consequences of any given movement, contributing to perceptual stability and a more accurate control over motor activity. An elegant study has shown that extrafusal muscle fibres begin to recover from a neuromuscular blockade with curare, which induces paralysis at a time when the muscle spindle receptors remain completely paralyzed (Luu et al. 2011). This study demonstrated that decreased responsiveness to gamma drive and a lower-than-expected reafferent spindle signal, was found in subjects who, as a consequence underestimated the weight lifted by their weakened muscles. Gamma drive in relation to muscle spindles, is the innervation that enables spindle receptors to remain sensitive during changes in length of the muscle itself (Bartels and Harrison 2025). In a separate study, Brooks et al. were able to successfully repeat the findings of Luu and co-workers, showing that when muscle spindle receptors in elbow flexor muscles are desensitized, muscle spindles exhibit a reduction in both weight (loading) and force perception (Brooks et al. 2013).

Conclusion

The present findings lend support to the evidence that proprioception and postural stability are regulated to some extent by muscle spindles, and that age-related changes in these receptors occur with individuals older than 60 years. The changes are identifiable in the acoustic myography parameters (E-score and ST-score) and are observed in a muscle-specific manner. In the upper limb it appears that the flexor declines later than the extensor muscle (m.Biceps vs. m.Triceps).

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Author contributions APH has been involved in developing the CURO and setting up a company to manufacture and sell the units; CURO-Diagnostics ApS, but he is not involved in the day-to-day business of the company, nor has he had any influence on the data collection. EMB has no interests to declare and was responsible for the protocol.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests APH has been involved in developing the CURO and setting up a company to manufacture and sell the units; CURO-Diagnostics ApS, but he is not involved in the day-to-day business of the company.

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