Aging and Myocontrol: Impact on Assistive Technology

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***Abstract*—We present experimental results on myocontrol, i.e., the control of myoelectric signals in young and aged healthy persons. The capacity of controlling myoelectric amplitude was assessed by means of a pointing task. Although young participants performed better on average, several aged participants performed quite well, too (good agers). Other findings were that myocontrol present specific speed-accuracy trade-offs, quite different from those of motor control, and that adaptive strategies were ubiquitous. From these results, we propose several guidelines to design myoelectric (EMG) devices for a wide range of customers, aged and young, skilled and unskilled. Finally, we suggest using pointing tasks to assess the efficiency of the different command spaces used in EMG devices, in complement to multi-joint movements measurements, usability evaluations and questionnaires.**

I. INTRODUCTION

Myoelectric (EMG) signals are used to control assistive devices [1] like prostheses [2], domestic systems [3] and computer interfaces [4,5]. Myoelectric signals are of special interest in case of severe motor disabilities because they can be captured from any preserved body part, e.g., forehead in case of spinal cord injuries, controlateral shoulder, biceps and/or triceps in case of severed upper limb [6].

However, *myocontrol* (i.e., the control of myoelectric signals) is by no means natural. The motor system is adapted to control movement and posture whereas myolectric activity normally remains covert. Myoelectric devices can thus be viewed as *artificial effectors* that require specific control strategies. The effectiveness of these strategies is a key factor for the success of EMG-based technologies, because insufficient control is a source of slowness, errors and frustration, which may cause rejection of the device.

Indeed, the degree of difficulty of myocontrol depends on the technology, i.e., the number and placement of the electrodes, the feature of the signal that is controlled and the signal processing algorithms. For instance, first-generation myoelectric arm prostheses driven by the contra-lateral shoulder [6] were more difficult to control than prostheses driven by signals captured directly on the stump [7]. However, even in this case, learning is not immediate and the control strategies may be non-natural. This can be experienced by any person (amputee or not) that tried to control a prosthetic arm.

As a working hypothesis, we may reasonably assume that i) whatever the technology, myocontrol has to be acquired, and ii) myocontrol is a specific modality that requires assessment. The basic capacities required for myocontrol, namely producing i) fast variations of myoelectric activity, ii) accurate myoelectric levels and iii) sustained myoelectric levels were thus assessed in a series of experiments with young and aged participants.

A classical motor task (pointing) was adapted to myocontrol. Participants had to reach a target with a visual feedback bar controlled by their myoelectric signals (amplitude of a differential electrode placed on the forehead and/or the hand), in different modalities and with different precision demands. The results have been presented elsewhere [8, 9] and will only be briefly reviewed here. The main objective of the present paper is to discuss the implications of these results for the design of myoelectric devices.

Three results of interest are examined. First, there is a general effect of age on performance (longer execution times, decreased accuracy), but there were remarkable exceptions: several aged persons performed as well as young participants. Second, several aspects of myocontrol are different from motor control. The speed-accuracy trade-offs are quite specific, and the timing plays an essential role (the tasks that are 'too fast' or 'too slow' are equally difficult). Third, task-dependent control strategies using different muscle synergies seem ubiquitous, and one of their effects is to homogenize the performance across different electrode sites.

Finally, we discuss the experimental assessment of myocontrol in different *command spaces,* characterized by the signal dimension (single electrodes, multiples electrodes, arrays...), the features to control (amplitude, frequency, timing,..) and the type of command (analog parameters vs. discrete regions).

II. TWO EXPERIMENTS ON MYOCONTROL

A. Tasks

The participants had to control the myoelectric amplitude captured by a differential electrode placed on the hand and/or the forehead. The EMG amplitude (RMS, averaged by bins of 50 ms) was represented by a vertical feedback bar on a computer monitor. After individual calibration, the participants had to reach a series of targets (Fig. 1) in two different modalities: by means of a fast contraction (*impulsion modality*) and/or by means of a sustained contraction that maintained the feedback bar within the target (*sustained modality*). There were two levels of precision: *low* (the range of the feedback bar was divided into 4 targets), and *high* (8 targets).

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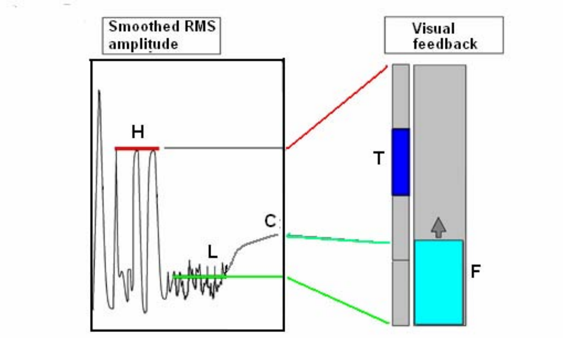

Figure 1. Pointing task. The smoothed RMS amplitude of myolectric signal (*C*) is converted into a feedback bar (*F*). The gain is normalized for each participant between rest level (*L*) and 3 maximal voluntary contractions (*H*). Participant adjusts the feedback bar(*F*) to reach the target (*T*).

B. *Young participants*

In the first series of experiments [8], the tasks were realized by two groups of young participants. For the *forehead group* (N=19, age=24.5 years), the bipolar electrode was placed above the right eyebrow (capturing EMG from frontalis, orbito-ocularis, fruncidor, levator parpebrae, corrugator, masseter). For the *hand group* (N=19, age=24.3 years), the electrode was placed on the thenar eminence of the dominant hand (capturing EMG activity from abductor pollicis brevis, flexor pollicis brevis, opponens pollicis, adductor pollicis transversalis).

The first finding was that *global performance was independent from the electrode placement*, i.e., the average execution times and rates of failure were similar with the forehead and the hand. Although there are alternative explanations, this equivalence suggests the presence of specific strategies that were equally efficient for each electrode placement. Such strategies may somehow compensate for non-optimal electrode placement, and maybe for electrodes that have been moved.

Second, *the tasks were markedly difficult when speed and/or stability were required*. This appeared clearly in the high precision condition. In the impulsion modality, the rate of failure was almost at the level of chance. In the sustained modality, the time required to stabilize the amplitude within the target were quite long. This suggests that in myocontrol the best performance may be obtained with moderate speed and accuracy demands, e.g., target amplitudes may have 25% tolerance, immediate return to rest level after reaching the target is not required, and stabilization within the target for a long period of time is not required.

Third, *the speed-accuracy trade-offs of myocontrol depended markedly on the task.* When the final amplitude had to be stabilized (sustained modality), the time to reach the target followed Fitt's Law [10], i.e., it increased as $\log_2$(precision/distance) (Fig. 2). When the amplitude had to return immediately to the rest level (impulsion modality), the time to reach the target was bow-shaped (Fig. 3). This suggests different control strategies and/or muscular synergies for extreme vs. intermediate amplitudes, and for final stabilization vs. immediate relaxation (as verbally confirmed by several participants).

C. *Aged participants*

The experiment was replicated with aged healthy persons (N=23, age=71.7) [9]. For practical reasons, we only used the hand electrode placement (forehead electrode was unpractical because some participants had wrinkled and/or fragile skin).

The first finding was that *the patterns of performance of young and aged participants were similar* (Figs. 2 and 3). Both groups presented the same type of speed-accuracy tradeoffs for the impulsion (bow-shaped) and the sustained modality (log-linear), and presented similar patterns of errors.

The second finding was that *the average performance of aged participants was poorer than that of young participants*, but mostly because *aged participants performed worse on the difficult tasks*. The effects of the speed demand (impulsion modality vs. reach time in sustained modality) and the precision demand (high vs. low precision and high amplitudes vs. low amplitudes) were significantly stronger for aged than for young participants. These results are consistent with the effects of age on the motor units and the motor system [11, 12].

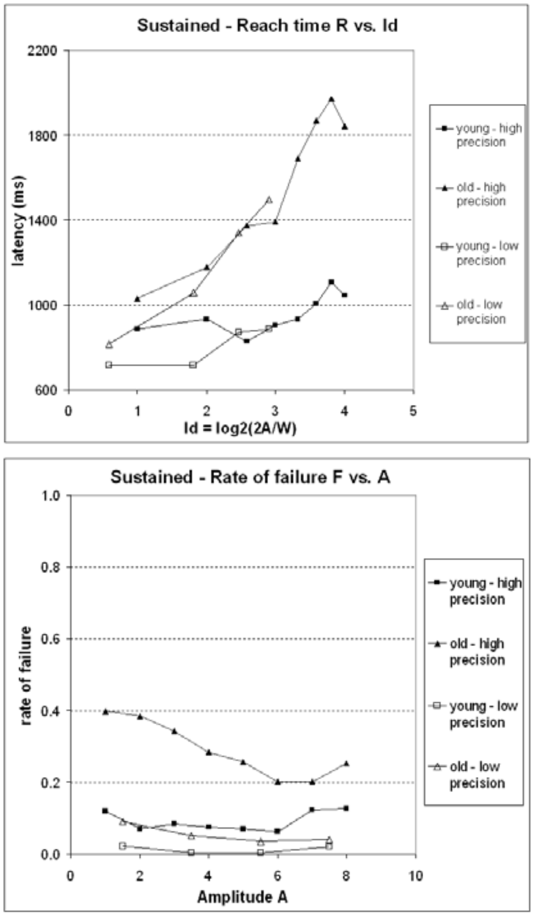

Figure 2. speed-accuracy trade-offs for young and aged participants in the sustained modalities.*Top*: execution time (logarithmic horizontal scale). *Bottom*: rate of failure (reprinted from [9]).

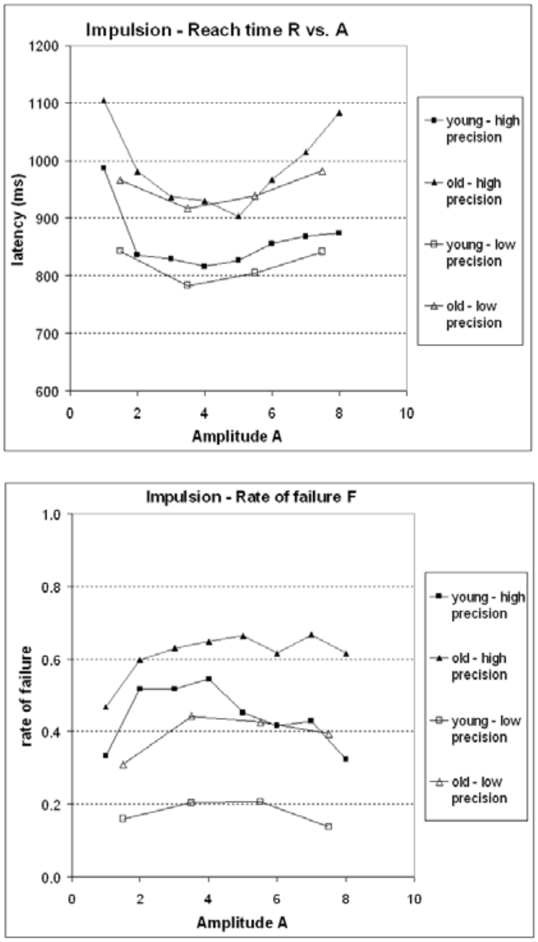

Figure 3. speed-accuracy trade-offs for young and aged participants in the impulsion modality. *Top*: execution time. *Bottom*: rate of failure (reprinted from [9]).

However, when individual performance was examined, *several aged participants performed as well as young participants* (Fig. 4). There were marked inter-individual differences between good and poor performers, in line with literature on good aging [13].

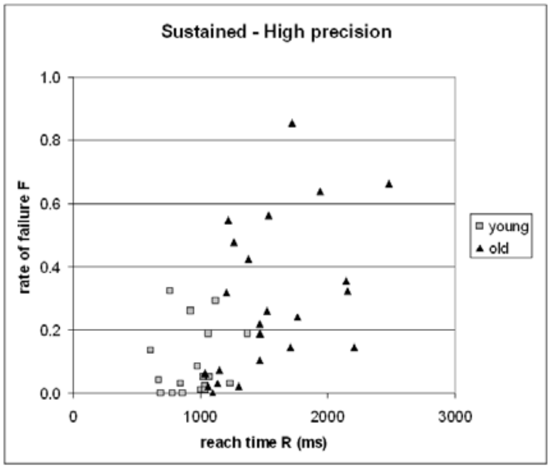

Figure 4. Individual performance of young (white squares) and aged (black triangles) participants represented in a plane speed-accuracy, for the sustained pointing modality in the high precision condition. Observe that some aged participants are within the group of young participants (reprinted from [9]).

In summary, i) specific, task- and amplitude-dependent control strategies and/or muscular synergies were also found for aged persons, ii) there was a general decline of myocontrol with age, but aged persons could still perform reasonably well simple myocontrol tasks iii) some aged individuals presented high capacities of myocontrol (*good agers*).

III. EMG DEVICES FOR YOUNG *AND* AGED PERSONS

The key observation that underlines the following sections is that *an assistive device that cannot be used efficiently by healthy persons cannot be used by disabled customers*. The design of EMG devices should thus take into account the pre- *and* post- morbid capacities of myocontrol.

In this context, elderly persons are of special importance given that they represent an increasing proportion of the disabled population. A parsimonious justification of this statement is that i) aged persons represent an increasing proportion of the overall population, and ii) the probability of disability increase with the lifetime.

However, designing special devices for elderly people may not be a valid approach, given that the aged population is heterogeneous in terms of skills and needs. A sounder approach in terms of costs and usability may be to design devices for both young *and* aged disabled customers, in line with the philosophy of 'Design for all' [14]. Two guidelines stem from our observations.

Design for all: accept short, imprecise and ill-timed commands. Aged individuals with limited capacity of myocontrol can successfully perform simple EMG tasks like controlling the amplitude of the EMG signal when the precision demand is low, and maintaining stability for short periods of times. High precision, high speed and/or sustained EMG activity may be demanding or even impossible for some aged individuals. EMG devices should thus accept short, imprecise and/or ill-timed commands in order to remain usable for all the disabled users, aged and young.

Design for skilled users: allow good performance. Skilled individuals, young and aged, may develop frustration if the potential of the assistive technology is below their own level of myocontrol. Frustration may also occur if the potential of the assistive technology is below the expectations of the users in terms of range of motion, velocity and strength. This may be the case for the growing amount of the population, young and aged, that practice sports and/or physical activities. EMG prostheses should thus allow fast and accurate movements and provide decent pressures and torques. EMG interfaces should allow high throughputs and/or a variety of commands.

Indeed, the challenge is to produce a rich *action space* (wide range of actions, torques and pressures and/or fast entry rates and multiple commands) from a poor command space (short, imprecise, ill-timed commands). It is worth emphasizing that if this challenge cannot be solved, or at least if some acceptable compromises cannot be found, EMG devices may be at best cosmetic accessories and will not be effectively used.

IV. DEVICES FOR MYO-, *NOT* MOTOR- CONTROL

Myocontrol has its own, specific speed-accuracy trade-offs. Even if the myoelectric signals that drive muscles or EMG devices are basically the same, they are controlled in a different way for natural movements compared to EMG devices. Two factors of importance are that the timing of commands and mechanical responses are different for limbs and prostheses, and that the feedback use different sensory modalities (mostly visual for EMG devices, proprioceptive and visual for natural movements).

It may thus be illusory to assume that myoelectric prostheses can be controlled 'just like' natural limbs. Indeed, nobody really assumes that the control of a prosthetic limb is entirely 'natural'. However, according to my personal experience, many engineers underestimate the amount or knowledge needed to master *any* technology, even the simplest (see for instance in [15] how 'natural' the use of a computer mouse is). Worse, mimicking natural body control with EMG devices may be counter-productive, just like it occurred with flying machines that mimicked birds' flight.

Design for myo- not motor- control. Rather than trying to mimic natural body control, an efficient command space should account for the specific speed-accuracy trade-offs of myocontrol, and should help in the basic actions that are especially difficult. For instance, non-linear transformations may be applied to EMG amplitude for fast commands, in order to maintain a constant level of difficulty, given that extreme amplitudes are more precise than intermediate amplitudes (Fig. 5).

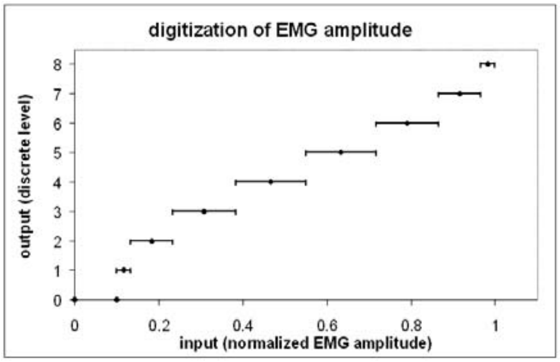

Figure 5.. Non linear digitizing scale for fast EMG commands. *Horizontal*: normalized EMG amplitude. *Vertical*: output discrete level (from 0 to 8). The scale is adjusted i) to allow rest-level variability and ii) to maintain a constant level of difficulty, given the curves of Fig. 3.

A second example would be providing mechanisms to help stabilizing myoelectric signals. Steady myoelectric amplitude is in fact a dynamical equilibrium [16], which is difficult to achieve. Simple linear filtering may help, but it may also distort fast commands, therefore non-linear mechanisms may be required.

Designing for myocontrol also means that the rules of design of movement-based interfaces should be validated prior to their application with EMG devices. For instance, the size and position of the components of graphical computer interfaces should minimize Fitt's index of difficulty for pointing movements as stated by the ISO norm 9241 [17, 18]. However, a different layout may be more adequate for EMG-controlled pointer, e.g., components placed at the borders of the screen may be easier to select by means of EMG impulsions (given the u-shaped speed-accuracy trade-offs found for this modality). In order to adapt EMG-controlled pointer to existing screen layouts, it may also be possible to use a variable gain so that the velocity of the pointer is reduced, and the precision increased, in the situations where EMG control is imprecise.

Finally, it should be emphasized that designing for myocontrol does not mean using unnatural commands (e.g., lift the eyebrow to move a cursor downwards on a computer screen). Natural EMG commands corresponding to well-practiced movements should indeed be preferred, in order to increase the feeling of familiarity and shorten the learning period.

V. FEEDBACK FOR EFFICIENT STRATEGIES

An implicit assumption of motor control is that simple movements, like pointing, are always performed in the same way. For instance, one of the conditions of validity of Fitt's law is that the same muscles and the same control strategy are used for a given task [8]. This assumption is challenged in myocontrol. For instance a participant explained that, according to the amplitude to produce with a forehead EMG electrode, he was lifting the eyebrows (frontalis muscle), half-closing the eyes (orbito-ocularis) or clenching the jaw (masseters).

In cognitive, perceptual and/or motor experiments, 'compensatory strategies' must be eliminated or controlled in order to obtain valid experimental results. In rehabilitation, compensatory strategies have negative effects, because they allow the patients to perform the tasks without actually executing the right movements.

However, in everyday life, strategies can be highly beneficial. Adaptive strategies allow reaching objectives in presence of difficulties, allow compensating for self-limitations, or merely break monotony in repetitive tasks [19]. For instance, elderly persons may perform quite well in motor tasks thanks to adaptive strategies that compensate reduced motor skills [20].

In the use of EMG devices, we can reasonably assume that all the users will initially develop adaptive strategies. Whether these strategies give way to automatisms or remain present in long-term practice is unknown, but in any case, they seem to be a major determinant of performance with EMG devices. Instead of trying to develop a stereotyped use of EMG devices, we propose to support the user in the development of his/her own effective and efficient strategies.

Give feedback for efficient strategies. We propose to consider four subtypes of feedback that may help to develop and/or use efficient strategies.

1) The *output* of the system, e.g., the position of the prosthetic limb or the position of a pointer on a computer screen. This information is always available for the user.

2) The *payload signal*, i.e., the features of the signal that are transformed into commands (e.g., the EMG amplitude). This information is available for computer interfaces [4] but a special setup is needed to display it for prostheses.

3) *Performance indicators*, e.g., rates of failures, execution times. This information may allow the user to self-estimate the efficiency of his/her strategies. It is available with specialized software [21], but is normally not displayed in computer interfaces.

4) *Signatures and features* of the signal itself, like spectrograms that inform on the active muscular groups [5], the level of noise of rest signal, etc. This type of information is normally not displayed in computer interfaces, because it is useless (only the payload signal is coded into commands). However this type of information may help the user in controlling globally his/her own myoelectric activity.

VI. ASSESSMENT OF MYOCONTROL

The observations presented here have been obtained with myoelectric amplitude and a single electrode pair. The frequency of capture, the type of signal and the filters have been tuned for our specific experimental task. However, for reasons presented elsewhere [8, 9], it is reasonable to assume that the general findings exposed here characterize myocontrol, not the specific EMG device used for the experiments.

It is clear that the absolute performance may change with the electrodes (single electrode, multiples electrodes, or arrays) and with the signal processing chain. It would thus be of interest to conduct myocontrol experiments in different *command spaces* (i.e., with the specific combination of myoelectric signals and features that will be transformed into commands). This may allow an objective comparison of different command spaces in terms of efficacy and efficiency.

Such experiments may use pointing tasks under a variety of feedback conditions. Pointing tasks are standard in motor control. Pointing tasks are also a common activity in computer interface, and they are part of the quantitative assessment of adaptive technologies [21]. From a behavioral viewpoint, pointing tasks are one of the most elementary goal-oriented behaviors. The presence of a goal may elicit strategies, which are a fundamental object of observation, and given the simplicity of the task, these strategies may be easier to observe than in complex, multi-joint movements, like finger movements [22].

Different pointing modalities (impulsion, sustained) may allow assessing the basic skills required to control a EMG device: produce rapid configurations of myoelectric activity, reach a desired configuration, and sustain a steady configuration. Also, the pointing tasks should be extended to represent different modalities of feedback, and/or different amount of feedback information. For instance, realizing the tasks in absence of visual feedback may give insights on non-visual EMG control, in which only proprioceptive information is used. This type of situation may be representative of the real use of an EMG device (prosthesis or computer interface) after the training phase.

Finally, in multidimensional command spaces the dimension of the signals must be reduced to the dimensions of the pointing task (typically mono o bi-dimensional), either by using synergies (compound EMG channels) or by projection (subset of EMG channels). This dimension reduction provides an opportunity to optimize the command space. By comparing performance with different subsets of channels and/or synergetic signals, it may be possible to reduce the number of channels on the basis of efficiency considerations.

VII. CONCLUDING REMARKS

The present article illustrated experimental results on myocontrol in aged and young populations. At the light of these results, we propose guidelines for the design of EMG devices adapted to all the customers, aged and young. These guidelines are: 1) accept imprecise, slow and ill-timed commands, given that it makes the control easier for all, especially for unskilled elderly persons. 2) Provide a rich action space given that users of all ages may require a level of performance adapted to their own skills and exigencies. 3) Design for myo- not motor-control, i.e., alleviate the specific difficulties of myocontrol. 4) Give informative feedback in order to elicit efficient strategies.

Finally, we propose to extend the experimental approach used here, i.e. pointing tasks realized by means of myoelectric signals, in order to compare and/or to optimize the command spaces of EMG devices, e.g., multi-channels electrodes, matrices of electrodes. Pointing tasks may provide information on the users' strategies and their efficiency. They may complement usefully traditional forms of technology evaluation, like assessment of complex multi-joint movements, usability tests and questionnaires.

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