Evaluation of adaptation to perturbed environments in elderly subjects

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Abstract— **Studies from different research groups observed that most of the age-related declines in cognition occur as a result of a decline in the efficiency of inhibitory mechanisms. Their theories evidenced that in advanced age there is failure to inhibit information that are irrelevant to current goals. In this work the implications that this phenomenon has on motor control system performance was discussed. Pointing movements on the horizontal plane were analyzed both in unperturbed dynamic environment (NF) and in the presence of a velocity dependent force field (VF) exerted by a robotic device both in young and elderly healthy subjects. Movement smoothness was monitored throughout the experiment in order to describe the evolution of the motor control adaptation process.The long term goal of our activities is to understand whether the ability of elders to learn new movements is modified by ageing.**

I. Introduction

Adults' age differences favoring the young have been demonstrated in a wide variety of tasks of fluid intelligence. Age-sensitive factors include (among many others): simple reaction time and choice reaction times, working memory (WM), episodic memory, special and reasoning abilities, mental rotation and visual search performance [1, 2]. The challenge for research on aging and age-related modifications is to identify the basic factors responsible for these declines. Probably the most pronounced age-related declines in physical and mental functioning are those observed in movement control, especially the slowing of many behaviours, more specifically the lower processing speed. Our hypothesis, confirmed by studies of several other groups [2], is that aging is associated with a deficit in executive functions that goes beyond the effect of a general slowing. In a switching motor task these function can be resumed in: 1) Focusing attention on relevant information while inhibiting irrelevant ones; 2) scheduling of processes, including switching of attention among tasks; 3) planning. In this respect Hasher and Zacks [3], asserted that, respect to young population, older adults have more problems passing from one task to another in the inhibition no-longer-relevant information.

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In this study sensorimotor adaptation in force field paradigms has been observed. A velocity dependent force field has been applied to the hand of participants while performing planar pointing tasks, by using a robotic manipulandum. Such a task is closely related to procedural learning [4], which often does not require complete conscious attention [5], but still reflects the ability of naturally reacting to an external mechanical stimulus and switching from one environment representation to another one. In fact, when human subjects are asked to move in a new dynamic environment an Internal Model (IM) of the external world is generated and/or updated by the CNS to achieve the desired trajectory of the arm [6]. Experiments carried out in the past by different groups suggested that the IM is a sensory motor transformation that maps the state of the arm into an estimate force [7]. The IM is learned with practice, and therefore updated continuously while moving, and appears to be a fundamental part of the voluntary motor control. Thus previous studies have reported that, when the field is applied, movements are perturbed presenting on their final part a typical "hook" with a direction opposite to the one of the applied force field. With practice, hand trajectories once again become smooth and close to straight line. Removing the force, so-called "after effects" appear represented by trajectories with hooks in the opposite direction of the ones described above [8]. This shows the capability of adaptation guided by the changes in motor strategies adopted by the Central Nervous System (CNS).

The aim of our experiments was threefold: (i) to study whether elders present similar after-effects; (ii) to observe the performance of the subjects in terms of smoothness of the movement in order to characterize the learning process and iii) to highlight whether and how the efficiency in regulation of IM is affected by the elderly reduced inhibition process.

II. Methods

A. Experimental procedure

During the experiments, the InMotion2 robot (IMT, Interactive Motion Technologies, Inc., Boston, MA, USA) was used [9] .

Eight right-handed young subjects (24 ± 4 years old) and eight right-handed elders 72 ± 5 years old) were involved in the experiment after providing informed consent. All the subjects were not affected by any neurological or orthopaedic disorder. Subjects were instructed to make point to point (back and forth) movements between a central position and one of the eight peripheral locations arranged in different directions (N,NE,E,SE,S,SW,W,NW) on a circle with a 14 cm diameter placed in the horizontal plane. These movements were performed in two different force field conditions: null field (NF, λ=0), and velocity dependent force field (VF):

$$F = \begin{bmatrix} 0 & \lambda \\ -\lambda & 0 \end{bmatrix} \dot{x} \qquad \text{with } \lambda = 20 Ns/m \qquad (1)$$

This force field perturbed subjects hand proportionally to their speed and perpendicularly to the direction of their movements. The experiment was composed of three main phases: subjects were first exposed to the null filed; then, after a period of practice with the VF force field, and eventually, after the adaptation to this new dynamic environment, they experienced again the null field. Experiments carried out by different research groups on this topics showed that healthy young subjects which experienced robot-generated force field that perturbed hand motion, were able to restore the original kinematics (adaptation process) of their movements after a short period of practice [10, 11]. Subjects achieved this result by cancelling the disturbance with an appropriate pre-planned pattern of forces. When the perturbing force was unexpectedly removed subjects showed after effects, revealed by movements errors in direction opposed to the disturbing force. In the present work, the evolution of the adaptation throughout the experiment, was studied breaking down each phase of the protocol in two different exercises: a first one related to the initial approach to the new dynamics (first movements), and a second one related to the consolidation of the adaptation process.

- Phase 1:
  - Exercise 1: Unperturbed Familiarization (32 movements to take confidence with the robotic device)
  - Exercise 2: Learning unperturbed dynamics (320 movements in NF to learn how to move in the NF)
- Phase 2:
  - Exercise 3: Early Learning (64 movements with the constant exposure to the force field)
  - Exercise 4: Final Training (320 movements in the force field)
- Phase 3:
  - Exercise 5: Re learning NF - After effect (64 movements without the presence of the force field)
  - Exercise 6: Final Washout (32 movements without the presence of force field).

In order to verify whether elders did not achieve the same performance as young subjects only because of their need for a more prolonged training two more elderly subjects where included in the experiment. They performed the same protocol with twice the number of trials during exercises 5.

B. Data Analysis

The position (R) of the handle gripped by the subject was recorded during the experiments with sampling frequency f_s =200 Hz. These data were low-pass filtered, by using a second order Butterworth filter with zero-phase and with a cut off frequency of 30Hz. R was differentiated to compute speed, acceleration and Jerk profiles, which were then smoothed with a fifth order dual pass low-pass Butterworth filter. Onset and offset of the movements were considered relative to the moment when hand speed passed the 2% of the peak of speed profile. To evaluate the efficiency of movements a normalized length path parameter was calculated with the following equation:

$$LL = \left(\sum dR\right) / L_t \qquad (2)$$

where dR is the distance between two points of the subject's path and L_t is the theoretical path length, represented by the distance of the two extreme points of the stroke. Higher values of LL corresponded to hand trajectories affected by larger errors [12].
Smoothness parameters S [13] was computed in order to quantify the evolution of movements fluidity:

$$S = -\frac{Jm}{V\max} \qquad \text{Rohrer parameter}$$

where J_m is the mean of the movement jerk. A high value of S indicate a smoother movement. The analysis was carried out by looking in a specific way at the different movement directions because of the anisotropy and orientation of inertia ellipse of the upper limb [14-16]. The learning process has been investigated by comparing the evolution of S throughout the experiment for each exercise and for each direction. Exercise 1 was excluded because errors and uncertainty of movements were due not to a modification or deficit of the motor control, but only to the inexperience to interact with the robot. The same analysis was carried out with the data collected for the two added subjects who performed more trials in the last phase of the experiment protocol.

C. Statistical Analysis

Differences between elderly and young length parameters were evaluated with a t-Test. An overall 2x6 (group x exercise) ANOVA for each direction was computed because the parameters behaviour changed with the movement direction. A Post hoc comparisons, Tukey's honestly significant difference criterion, was then used to determine which of the exercises were mainly responsible for the statistical differences.

III. Results

The t-Test made on the length line (LL) parameter showed that there were no significant differences on the entity errors committed by elderly and young subjects throughout the experiment (p=0.27). Differently from what expected this parameter does not discriminate for the two groups. In Fig 1, hand path and speed profile of a young and an elderly subjects are showed as representative of the two age group behaviour; elderly subjects presented repetitive changes in the speed profile due to alternation of acceleration and deceleration phases. These discontinuities were not significantly reflected by the hand path that was bell shaped in both the two subjects. The consequence was a length line parameter equal in both the two groups in the different experiment sessions.

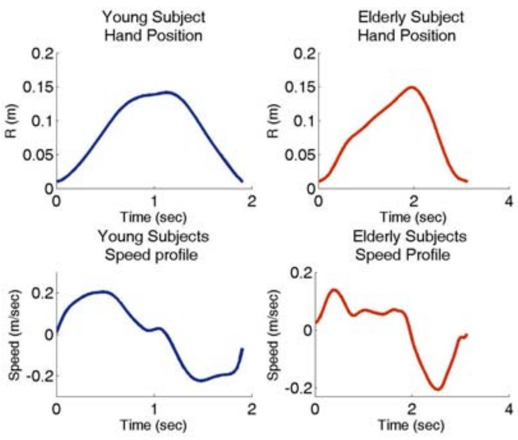

Figure 1 Hand position and speed profile of two subjects, a young and an elderly person respectively. Discontinuities are present in elderly speed slope as a reflex of many accelerations and decelerations phases while moving. Hand path is bell shaped profile and there is not a particular evidence of age related differences.

Elders performed point to point movements more slowly than young subjects (p<0.01). For the two groups and for each of the eight directions, S values and distributions were evaluated for the six different exercises. In general, we expected: 1) to observe that after a period of familiarization with the robotic device, (exercise 1) subjects trained in NF (exercise 2) learned how to improve their performance moving more and more in a feed-forward manner; 2) when exposed to the VF field the automatism acquired in the previous session made subjects move (exercise 3) less smooth, with many errors, and with typical hooks in the proximity of the goal point; 3) after practice in the field (exercises 4) subjects succeeded in improving the quality of their movements; 5) as a consequence of the learning process, when VF was turned off, the trajectories traced by subjects presented typical after-effects.

Our results confirmed these expectations both for young, and for elderly people (Figure 2). In the final wash-out the smoothness had to increase again as a consequence of the good effect of the training. In Fig. 3 the evolution of S during the experiment for elderly and young people is shown. These results confirmed that elderly subjects did not present a behaviour coherent with the learning trend, and showed the peculiar tendency not to improve the smoothness (and in many direction even reduce it) in the sixth exercise, with respect to the values observed at the beginning of the experiment (exercise 2).

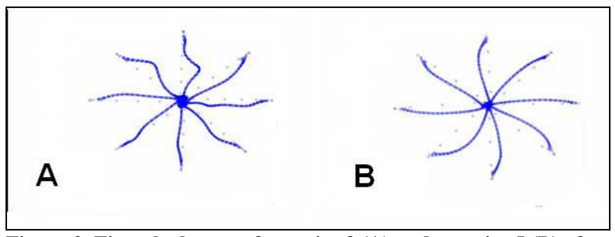

Figure 2 First clock turn of exercise 3 (A) and exercise 5 (B) of an elderly subjects. Trajectories were curved on the right at the exposure to the VF force field, and in the opposite verse when was removed it.

Young subjects instead took advantage of the training and, after the re-learning of the NF dynamics in the exercise 5, improved their performance. Movement smoothness increased its values with respect to the initial ones. The two factors ANOVA was applied as described in methods and results are showed in Table I.

As expected elders were less smooth than young subjects: the group effect was significant (see Figure 3). With the exception of one direction, S varied across the exercises of the experimental protocol, confirming the presence of a trend in the movement smoothness evolution during the adaptation process (see Table I). The Tukey hsd criterion revealed that, in the case of elderly, these differences were due principally to higher values of S in the second exercise and to lower values of the same paramenter soon after the field was applied (exercise 3). In the young group, differences between sessions were caused both by a significant decrease of smoothness in the third exercise, and by a higher value of it in the sixth exercise. A part for two directions there was interaction between groups and exercise sessions, confirming that elderly and young group evolved differently during the experiment. In order to understand whether the lack of improvement after the training session of elderly subjects could be correlated to the number of trials used in the de-adaptation phase of the exercise, rather than to a modification in the motor control strategy, two more subjects were included in the experiment, and were asked to make the same protocol experienced by the past elderly group, with twice number of trials in exercise 5.

We repeated the same smoothness analysis as before, and compared the results obtained considering, once the mean values of the eight clock turn, and then of only the first 4 clock turns, as in the previous experiment protocol. In Figure 4 the S trend throughout the exercises is represented in four of the eight directions. When subjects performed a higher number of trials (blue line) the evolution of their movement smoothness behaved as observed for young group in Figure 3. At the end of the relearning phase movements kinematic was completely restored and, in the final washout (exercise 6, two clock turns), there was an improvement of S with respect to the beginning of the training session (exercise 2). If subject performed only 4 turns instead of 8 (red line), at the end of the re-adaptation phase they would not recover enough.

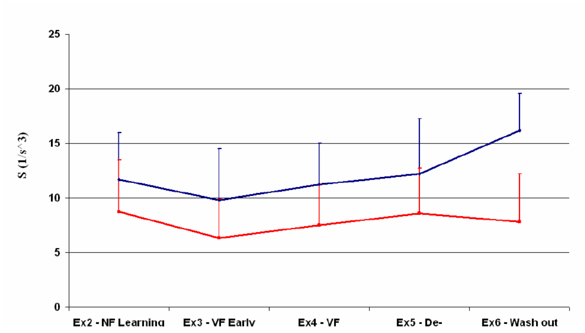

Figure 3 Evolution of the of the smooth parameters throughout the experiment in one of the eight direction; Errorbar blue= young group, Errorbar red=elderly group. The behavior is similar for all the other directions.

Table 1 ANOVA 2_ways (group x exercise) made for both the two smoothness parameters S1 and S2. Gr= group, Ex=exercise session, INT interaction.

S1	*GR*	*EX*	*INT*
N	P<0.01	P<0.01	0,614
NE	P<0.01	P<0.01	0,045
E	P<0.01	P<0.01	0,012
SE	P<0.01	P<0.01	0,029
S	P<0.01	P<0.01	0,031
SW	P<0.01	P<0.01	P<0.01
W	P<0.01	0,063	0,076
NW	P<0.01	P<0.01	P<0.01

IV. Discussion

The aim of the present study was to compare the performance of elderly and young subjects while learning to compensate a new dynamics through the use of two different kinematic parameters.

When force fields were turned off the trajectories of young and elderly people presented classical after-effects. This shows that elderly people did not lose the capability to adapt to a novel dynamics although their trajectories often presented some discontinuities. To characterize the performance of elders in detail, the evolution of trajectory smoothness through the experiment was investigated. The analysis made with S showed that elderly subjects did not improve their smoothness as expected. In particular the principal differences were found passing from the VF force field to the null filed, the de-adaptation phase. During the final washout elders often barely achieved the performance shown at the beginning of the experiment. This result confirmed that with aging the movement reorganization ability is reduced so that elders did not benefit of the training with the same efficiency as young subjects. Different conclusions could be made increasing the number of trials, as described in the Figure 4.

Elders in the sixth exercise presented movements smoother with respect to the ones performed in the second exercise, showing that they restored completely the kinematics of movements, and improved the fluidity of their motion because of practice.

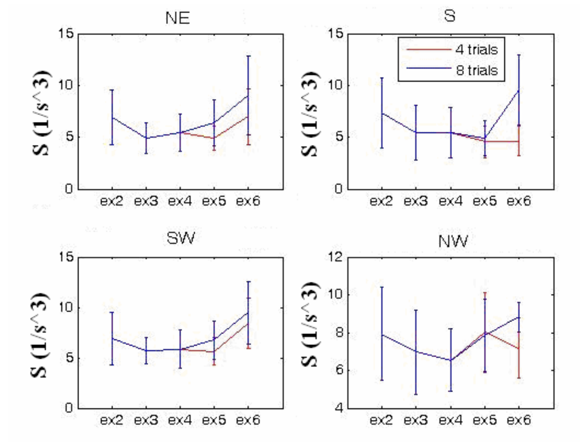

Figure 4 Comparison between the two experimental protocols of S1 evolution for the two added elderly subjects: red line is relative to the 4 clock turn protocol; blue line showed the behavior when subjects were trained twice.

Thus, in conclusion, our results suggest that young subjects are faster to reorganize the motor control strategies to take into account a novel dynamics, while elders need more exercise. This is probably caused by a reduced ability of the elders to update quickly their IM. The reasons of such a behavior could be found for example in the delays of the sensory feedback that compromise somehow basic response speed and decision making , but other consideration could also be done [17].

There are several studies [18] that deal with the adaptation and de-adaptation process in humans. It has been demonstrated that the time constant to adapt to a novel dynamic (in terms of number of trials needed to restore the correct kinematic of movements), is higher that the one needed to de-adapt. This was confirmed, in the case of young subjects, also in our experiment. It is evident that at the end of the third exercise (64 trials) the fluidity of movements was lower respect to the one observed in the null field condition. Comparable performances were achieved only at the end of the fourth exercise, but subjects needed less number of trials (the same of exercise 3) to de-adapt. This was not the case of elderly group: to achieve the same trend of young group the number of trials has been doubled; one could say that time constant increases with the aging process, but it could be possible that, besides the value, also the structure of the process changes. Speculating on these topics one could also argue that during both the adaptation and de-adaptation phases, considered in some way as a switching task, elderly presented problems in deciphering the novel information coming from their sensorimotor feedback because of their difficulty with inhibiting no- longer-relevant representations and selecting the novel ones. This could be the cause of the presence of residual activation of the previous no longer relevant task-set (i.e., representation of the person's currently operative goal, together with an associated rule or a set of parameters that determine which stimuli are relevant and how to respond to them, [19]) and could lead to a longer transition phase in which conflicting stimuli could be processed, thereby slowing down the response and the reorganization of the IM.

Thus, beyond a general slowing, the cost of switching between different rules could be also altered. Further experiments will be developed in order to investigate this issue.

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