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The use of an exoskeleton to investigate the self advantage phenomenon

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Abstract— **This paper presents an upper extremity exoskeleton with an original application in neuroscience. The novelty of this study is the investigation of the self-advantage phenomenon under various experimental conditions. Usually this kind of experiments lies only on human visual ability to explicitly and/or implicitly recognize their own arm movements. Using an exoskeleton to replay recorded trajectories allows to give another perspective to the previous studies in including the proprioceptive ability of humans. Twelve healthy subjects were involved in this study. The results show that the self advantage phenomenon is even more present in the implicit tasks.**

I. INTRODUCTION

In the last decade, several efforts have been carried out to understand the neural processing of the human own-body-knowledge. The most prominent work in this domain deals with the functional and anatomical aspects of self-face processing and recognition [1]–[3]. However recent advances in neuroscience show that humans are also able to recognize their own body and body parts [4], [5].

In [6], Frassinetti *et al.* investigated the different levels of visual self processing in static and dynamic experimental displays for both healthy subjects and right brain damaged patients. Their results showed that despite the loss of self-processing ability in static displays (when looking at limb photographs), the right brain damaged patients retained a considerable aptitude for self-processing in dynamic displays (when looking at videos of moving limbs). These findings provided neuropsychological evidence that the movement of the body parts can favor the self/other distinction, and self-processing of static and dynamic images are functionally different.

To date, most of the previous works have been carried out using images and video recordings of the subjects' body part and self-advantage has been documented solely in implicit tasks [7]. In this paper, an upper extremity exoskeleton is used for the assessment of the neurological aspects underlying the visual and proprioceptive processing of the arm motion. It offers thus a novel approach for the investigation of the own-arm-knowledge in dynamic activities. Both explicit and implicit self-recognitions tasks can be tested. The next section is dedicated to the presentation of the exoskeleton used and the control law implemented to make it transparent for the users. Section 3 presents the experimental results obtained and finally the last section discusses the main conclusion drawn from this study.

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II. MATERIALS AND METHODS

A. Description of the upper extremity exoskeleton

The exoskeleton used during this study is a four degrees of freedom serial robot. The shoulder complex is represented by three orthogonal revolute joints intersecting in one point and forming a spherical joint. It covers the four basic degrees of freedom of the arm:

- the shoulder internal/external rotation;
- the shoulder flexion/extension;
- the shoulder abduction/adduction;
- the elbow flexion/extension.

Figure 1 shows a photography of a subject wearing the exoskeleton and presents the kinematic chain of the exoskeleton. The right arm of the subject is linked to the exoskeleton by externa arm and wrist holders with pressure adjustable internal pneumatic holders.

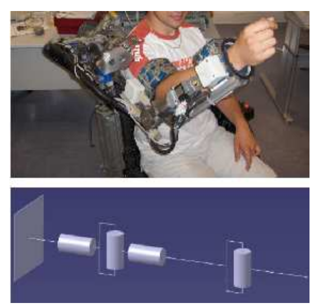

Fig. 1. The upper extremity exoskeleton with its 4 four active degrees of freedom

The exoskeleton's dimension are adaptable to fit different users with different body sizes. The shoulder height and width as well as the upper arm length can be modified by DC motors mounted on worm gears. Each active degree of freedom is connected to a brushless motor driven by an Ultra1500 drive operating ar a sampling frequency of 5 kHz. The control paradigms are developed with Matlab/Simulink and linked to the drives *via* a dSPACE control card. More details about the exoskeleton can be found in [8].

B. Control of the exoskeleton

To study the motion of subjects wearing the exoskeleton, the later should not disturb the user while accomplishing the desired motion. It is thus necessary to make the exoskeleton transparent for the users. For this purpose the effect of gravity on the exoskeleton should be compensated.

It exists different methods to compensate the gravity. One is based on passive external gravity balancing mechanisms (cable driven pulleys, spring systems, *etc.*) [9]. For practical bulk considerations, this method could not be applied on our exoskeleton. Another solution lies on relatively complex identification procedures [10] or with simplifying assumptions [11].

For the gravity compensation control, the method used for this exoskeleton is an original one described in [8]. It is only based on the geometric model of the robot, and a finite set of static torque measurements in appropriately chosen joint configurations. This method is quite complex in its development but once formulated its application is very simple. However to obtain a full transparency it is also necessary to compensate the friction effects. For this compensation, classical identification method was used: the dry and viscous friction parameters were identified by applying, for each joint, a series of single joint movements with different constant velocities.

The resulting friction compensation model was applied with the gravity compensation on the exoskeleton in order to improve the overall transparency.

C. Experimental Protocol

As already presented in the introduction, the aim of these experiments is to investigate the self advantage phenomenon. the experiments concern 12 healthy subjects who volunteered to participate in the study. Their ages range from 24 to 30 years old and they are all right handed. They were divided in three groups of four. They would be referred to as (A_1, B_1, C_1, and D_1) for the first group, (A_2, B_2, C_2 and D_2) for the second group, and (A_3, B_3, C_3 and D_3) for the third group. The members of the same group have similar heights and body sizes. The same procedure was repeated for each group. The experimental protocol consists of two stages: the recordings and the replays.

The recordings

In the first stage, the user sits in the wheel chair and wears the exoskeleton, the latter being operated in the passive recording mode. The gravity and friction effects are compensated to enable free and transparent handling. Two balls are placed on the edge of a horizontal table at arm's reach in front of the user and leveled with his shoulder. They are 20 cm apart and symmetric with respect to a saggital plane passing through the shoulder joint (Figure 2).

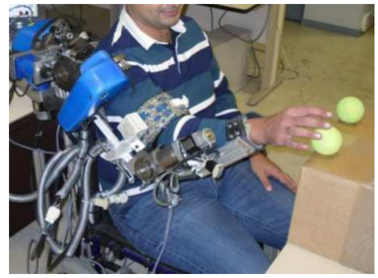

Fig. 2. An user executing a reaching motion

For each group, every subject (A_i, B_i, C_i, and D_i with $i \in [1,3]$) is asked to perform, while wearing the exoskeleton, two series of repetitive motions: 12 motions to reach and grab the ball to the right, and 12 motions to reach and grab the ball to the left. For each series, the first and the last motions are eliminated. 6 motions are then randomly chosen among the 10. In total, 48 motions are saved for each group.

The reconstruction

Every subject is associated to a one-way partner from his group i with $i \in [1,3]$: B_i partner of A_i, C_i partner of B_i, D_i partner of C_i, and A_i partner of D_i forming 4 couples per group. A program creates, for each subject, random sequences of 24 consecutive motions constituted by his own and his partner's reconstructed motions. Thus, each situation (subject, ball position) is presented by 6 motions. 6 different sequences of 24 motions (the same 24 motions in different order) are created for each subject and 6 different experiments will be subsequently carried out for the assessment of the visual and proprioceptive processing of his own arm motion. In order to achieve reliable and unbiased results, before and during the recording process, the subjects were only informed about the physical interaction with the robot, but not about the nature or the particulars of the experiments. The recordings were conducted with one subject at a time, without any communication between the subjects before the end of the whole experimental procedure.

The replays

In the second stage, the exoskeleton is operated in an active trajectory tracking mode. For every subject, six different experiments are conducted. In each experiment, the exoskeleton replays one (randomly chosen) of the six sequences of 24 motions previously constructed for the user. Each sequence is replayed only once.

The experiments are presented as follows:

1) *Self recognition in Proprioception* - ***SP***: the subject sits in the wheel chair and rests his arm passively in the exoskeleton. His eyes are closed while the robot replays the corresponding motion sequence. At the end of each motion, he should say whether it was a replay of one of his own motions or not.
2) *Self recognition in Egocentric Vision* - ***SEV***: the subject sits in the wheel chair without putting his arm in the exoskeleton, and watches a replayed sequence of 24 motions. At the end of each motion, he should say whether it was a replay of one of his own motions or not.
3) *Self recognition in Allocentric Vision* - ***SAV***: the subject sits facing the exoskeleton (approximately at 2m distance) and watches another sequence. At the end of each motion, he should say whether it was a replay of one of his own motions or not.

These experiments' aims is to to test the explicit conditions.

Three other experiments were conducted in similar conditions, but for the processing of the motion direction (the position of the ball):

4) *Position recognition in Proprioception - **PP***;
5) *Position recognition in Egocentric Vision - **PEV***;
6) *Position recognition in Allocentric Vision - **PAV***.

In these experiments, the subject should say, at the end of each motion, on which side was the corresponding ball. **These experiments' aims is to to test the implicit conditions.**

The objective of these experiments is to investigate the self advantage phenomenon in recognizing the own-body movements among others. As presented in this part, this investigation is conducted for both visual and proprioceptive recognition. The self advantage can be manifested explicitly or implicitly. **The explicit manifestation of self-advantage can be observed in the three self recognition experiments**; it is characterized by a higher level of good answers from the subject for the replays of his own motions. In the position recognition experiments, **even though the subjects are not asked whether it was their own motions or not, the self advantage can still be manifested implicitly**; it is also characterized by a higher level of good answers from the subject for the replays of his own motions.

III. Results

In total, 72 trials were performed (6 experiments per subject). In each trial, 24 answers corresponding to the 24 replayed motions were provided by the subject. For each experiment, the mean values and the standard deviations (std) of the total proportion of good answers as well as the total proportion of good answers in own-motion replays and in other's motion replays are given in the table I.

TABLE I
RESULTS SUMMARY OF THE CORRECT ANSWERS

Exp. conditions		SP	SEV	SAV	PP	PEV	PAV
Total	mean (/24)	18.75	16.54	15.25	17.75	20.44	18.17
	std	1.66	1.62	2.38	2.3	1.78	1.9
Self	mean (/12)	8.58	8.83	7.83	9.33	11.42	10.25
	std	1.38	1.64	1.7	1.3	1	1.14
Other	mean (/12)	10.17	7.67	7.42	8.42	9	7.92
	std	1.47	0.89	1.67	1.78	1.76	1.68

These results are summarized in the figure 3. It shows the percentage of good answers and the corresponding standard error of the mean (SEM) in each experiment for both self and other's motions.

To complete these results, ANOVA tests have been performed. This kind of analysis allows to test the existence of a significant difference between the observed means of several samples drawn from several populations respectively. The different sets of observations carried out in our experiments can be categorized under three main effects:

- Modality (Proprioception, Egocentric vision, Allocentric Vision)

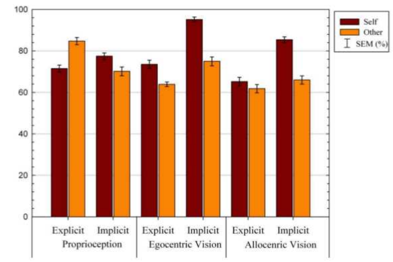

Fig. 3. Percentages of good answers and SEM

- Type of task (Explicit, Implicit)
- Ownership (Self, other)

The main effect Modality was significant (p<0.003) and explored with Newman-Keuls post-hoc test. Subjects appeared to perform overall less correctly in the allocentric vision (AV) Modality (69,6%) as compared to both the proprioceptive (P) (76%; p<0.005) and the egocentric vision (EV) Modality (76,9%; p<0.005). The difference between the two latter Modalities was not significant (figure 4).

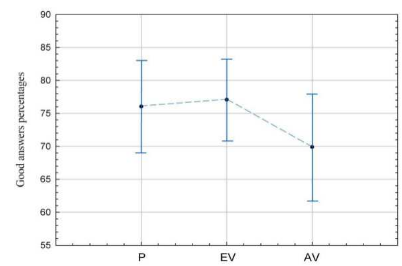

Fig. 4. 95% confidence intervals for Modality levels

The main effect Type of task was also significant (p<0.003); the subjects' performance was more accurate in the implicit task (left / right position judgment, 78.2%) than in the explicit task (self / other judgment, 70.1%). This main effect was expected, as the position where the exoskeleton grasped the ball would indeed be easier to be recognized when compared to the task of deciding whether the movement was or not ones' own (figure 5).

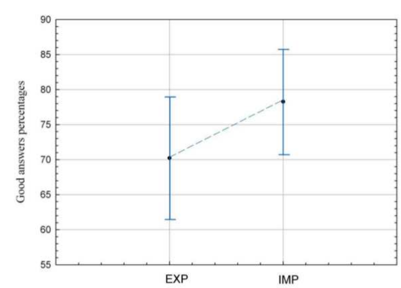

Fig. 5. 95% confidence intervals for Type of tasks levels

The main effect Ownership was also significant (p<0.004); participants were overall more accurate when performing the recognition tasks on their own movements (78.1%), as compared to somebody else's movements (70.3%). This result seems to indicate the presence of a general benefit to performance with self-related movements, and is in line with the predictions of our hypothesis (the self-advantage phenomenon) (figure 6).

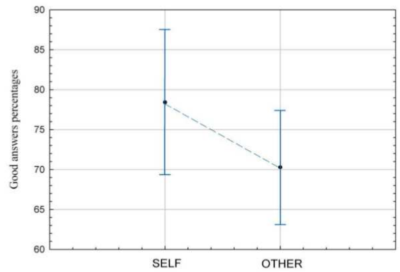

Fig. 6. 95% confidence intervals for Ownership levels

For the purposes of the present study, it is interesting to compare the effect of multiple levels of two factors simultaneously (interactions) on the mean value of a single variable in a population. In our case, the most interesting significant interaction is the Type of task * Ownership as it indicated that subjects performing the implicit task were more accurate when experiencing their own movements (86.1%) as compared to somebody else's movements (70.4%, $p<0.001$), irrespective of the Modality of movement exposure. No difference was observable in the explicit task (figure 7). Therefore, the self-advantage was clearly present only in the implicit task, when the self-other dimension of the movements is completely task irrelevant, as subjects are judging the spatial position of the exoskeleton's grasping movements.

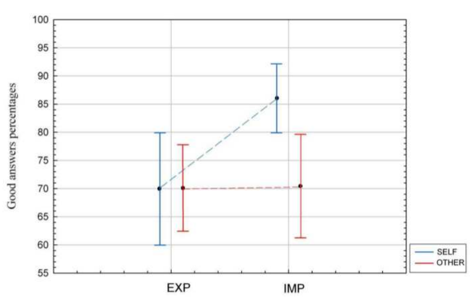

Fig. 7. 95% confidence intervals for interaction levels (Type of task * Ownership)

These results fully support the hypothesis that the human brain is capable of implicitly processing the ownership not only of body parts [12], but also of the movements they perform. Overall, these works suggest that the self-advantage found in behavioral paradigms applies both to body ownership and agency of actions.

IV. Discussion and Conclusion

Upper extremity exoskeletons are rarely employed outside the rehabilitation and motion assistance applications. This paper presents a novel approach for the assessment of the own-arm-knowledge in dynamic activities using an upper extremity exoskeleton as a data acquisition and recording device, and a realistic physical motion replay tool. This tool provides more accurate and rich experimental environment compared to the classical methods that are often used in this type of investigation, and the possibility of exploring new aspects of self advantage manifestations.

The experimental results were presented and analyzed. They provided substantial variance between different experimental conditions and robust evidence of self-advantage manifested in the implicit tasks. Therefore, human brain is believed to be capable of implicitly processing the ownership of body movements.

Similar experiments are being conducted on three samples of twelve healthy subjects to further inspect the self-advantage manifestations and possible interactions in various types of arm gestures with subtle differences. The visual appearance of the exoskeleton should also be taken into account to determine if it has any effect on self-advantage phenomenon or not.

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