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Arm-trunk coordination in wheelchair initiation displacement: A study of anticipatory and compensatory postural adjustments during different speeds and directions of propulsion

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ABSTRACT

Arm-trunk coordination during the initiation of displacement in manual wheelchair is a complex task. The objective of this work is to study the arm-trunk coordination by measuring anticipatory and compensatory postural adjustments. Nine healthy subjects participated in the study after being trained in manual wheelchair. They were asked to initiate a displacement in manual wheelchair in three directions (forward vs. left vs. right), with two speeds (spontaneous vs. maximum) and with two initial hand's positions (hands on thighs vs. hands on handrails). Muscular activities in the trunk (postural component) and the arms (focal component) were recorded bilaterally. The results show two strategies for trunk control: An anticipatory adjustment strategy and a compensatory adjustment strategy with a dominance of compensation. These two strategies are influenced by the finalities of displacement in terms of speed and direction depending on the hands positions. Arm-trunk co-ordination is characterized by an adaptability of anticipatory and compensatory postural adjustments. The study of this type of coordination for subjects with different levels of spinal cord injury could be used to predict the forthcoming displacement and thus assist the user in a complex task.

Keywords:

Coordination

Arm-trunk

Human movement

EMG

Wheelchair

1. Introduction

During upper limbs movement in a sitting position, and from the anatomical point of view, the trunk is interposed between the support basis and the effectors members. It has a key role of support which participates in the movement execution (Fayad et al., 2008). Therefore, a precise coordination between arms movements and trunk movements is necessary. For Lee et al. (2008), in adults, coordination is often associated with the notion of 'functional synergy', which means the spatiotemporal organization of muscles and joints related to the task success. This coordination is ensured by the central nervous system (CNS) by the mean of adaptive motor commands according to the forthcoming movement (Robertson and Roby-Brami, 2011). Therefore, the CNS

sends motor commands to the focal component for movement execution as well as to the postural component to ensure anticipatory postural adjustment (APA) and compensatory postural adjustment (CPA) for the gesture adequacy to the desired goal by the motor execution (Chikh et al., 2016). The postural component has a counter-perturbation role caused by the focal movement which will alter the postural balance (Bouisset et al., 2000), a role of protection of standing postural stability (Aruin et al., 1998; Wang et al., 2014) as well as a participation role in the movement execution according to its parameters (Saling et al., 1996; Flanders et al., 1999; Allison et al., 2008).

One of the central problems in experimental studies of motor control is to understand the movement control as well as the ability of the CNS to anticipate and simulate the behavior of the motor apparatus

(Blakemore and Sirigu, 2003). The adaptability of the APA to the movement parameters is generally observed according to different dominant characteristic(s) of the forthcoming movement, such as speed, direction, or weight (Chikh et al., 2016), also according to different sources of constraints imposed to the postural system like biomechanical, temporal and psychological sources (Yiou et al., 2012).

For disabled persons, with an insufficient lower limb functionality to move in bipedal position, locomotion can be ensured using a manual wheelchair. The control of the bi-manual propulsion and the displacement in manual wheelchair is complex and remains considered as an inefficient way of locomotion (De Groot et al., 2013). Few studies have been interested in the arm-trunk coordination during displacement in wheelchair and many works are still necessary in order to better understand, improve or even assist this mode of locomotion. This mode of locomotion must be controlled in three dimensions (Oh et al., 2008) and has two levels of perturbation: propulsion (segmental kinematics) and displacement (inertia of the subject-chair couple). Arm-trunk coordination is thus paramount. The abdominal and dorsal muscles contractions, in particular at the end of the recovery phase and at the beginning of the pushing phase ensure the sufficient trunk stability to meet propulsion requirements (Yang et al., 2006) and this in parallel with the activation of the arms muscles (Louis and Gorce, 2010).

To date, there are ample investigations on manual wheelchair propulsion when the subject is already in displacement. However, to our knowledge, the passage from static to displacement phase of propulsion has not been the object of previous study. This transition phase will be called initiation of displacement in manual wheelchair. The arm-trunk coordination at initiation of displacement in manual wheelchair is paramount considering the important forces to generate to overcome the inertia of the manual wheelchair and the subject. The level of adaptability of this coordination, or more generally of the muscular patterns during the initial phases of propulsion are of particular interest because more abrupt motions likely occur more frequently throughout the day than smooth steady state propulsion (Morrow et al., 2010). This, coupled with the fact that propulsion is inherently repetitive and inefficient, supports the notion that propulsion improvements could be impactful to health and wellbeing.

In order to study this postural control during the initiation of displacement in manual wheelchair, that is to say the anatomical and functional demands, the presence of the whole postural component must first be identified as well as the focal muscle that will allow the temporal division of the APA and CPA windows. The activation time of the focal muscle is defined as the T_0 'time zero' (Aruin & Almeida, 1997). Then, we must take into account the fact that the movement of the two arms is complex in view of the degrees of freedom (Bernstein, 1967) in relation to the movements of the trunk and the head. This makes difficult to identify the focal muscle or *prime mover*. Finally, the user population of manual wheelchair is very heterogeneous as a result of the deficiency or deficiencies that led to this locomotion in manual wheelchair. To define the population to be studied to invest this trunk coordination via APAs and CPAs requires then to make choice of functional categorization.

Against this set of difficulties, two methodological solutions have been chosen: (i) the training of a homogeneous group of healthy able bodied subjects in manual wheelchair which will enable the whole focal and postural muscles to be studied; (ii) measuring the muscular contraction of the entire focal component to select the *prime mover* at each trial.

Thus, the aim of this work is to study the arm-trunk coordination by measuring the APAs and CPAs in the initiation of displacement in manual wheelchair. We hypothesized an adaptability of muscular patterns to the different finality of initiation of displacement in manual wheelchair in terms of speeds and directions according to each hands position.

2. Method

2.1. Participants

Nine healthy subjects (eight men and one woman) have voluntarily participated in the experiment. Means and standard deviations of age, weight and height were respectively 23.6 ± 7.1 years, 75.2 ± 8.8 kg and 180 ± 10 cm. The subjects (novice, healthy able bodied) received the basic knowledge of wheelchair travel (how to propel the wheelchair in straight line, how to turn...) and were trained as part of a course in adapted physical activity. All subjects signed an informed consent approved by the university's institutional review board.

The inclusion criteria are: (1) have theoretical knowledge on propulsion in manual wheelchair; (2) have a minimum of 15 h on manual wheelchair handling; (3) be right handed; (4) be motivated to participate voluntarily in this study. The exclusion criteria are: (1) have a neurological, cardiopulmonary, muscular or joint disease that can alter the propulsion in manual wheelchair; (2) be under medication that may affect the equilibrium, propulsion or understanding the instructions.

2.2. Tools, variables and measures

2.2.1. Tools

Electromyography EMG: electrodes (FOAM Ag/AgCL-oval 32 mm * 36 mm) were placed bilaterally (left (L) and right (R)) on the following muscles for the two components: (1) the focal component; deltoid anterior (DA), deltoid posterior (DP), biceps brachii (BB) and pectoralis major (PM) and (2) the postural component; rectus abdominis (RA), obliquus externus (OE), and erector spinae (ES). This step was carried out in accordance with the recommendations of Hermens et al. (2000) by the same experimenter. Muscular activities were recorded using the "Bipolar Zero wire 16-channel AURION amplifier". Data sampling was accomplished at 1000 Hz. Manual wheelchair: the same manual wheelchair, ACTION2000, was used by all subjects. Data recording and processing were performed using HP pavilion dv7 Notebook PC.

2.2.2. Variables and measures

The relative intensity of APAs: corresponds to the relative intensity between -100 and $+50$ ms with respect to T_0 .

The relative intensity of CPA: corresponds to the relative intensity between $+50$ and $+200$ ms with respect to T_0 .

2.3. Tasks and procedures

2.3.1. Before experiment

Each subject is informed of all steps of the experiment and signs an informed consent. After abrading the upper part of the epidermis with an abrasive face sponge and cleaning the skin with alcohol, the electrodes were placed bilaterally. A standardized warm up of 5 min was made by each subject (move forward, turn right and turn left 5 times in each direction, at two speeds: spontaneous then maximum). Before starting the actual experiment, the subject makes three passages without recording to check the proper functioning of the acquisition and the understanding of the experimental conditions.

2.3.2. Wheelchair position and instruction

Subjects positioned the rear wheels according to the direction of displacement requested (forward, right or left). For forward direction, subject facing forward; for left direction, subject facing rightward (90°); for right direction, subject facing leftward (90°) (Fig. 1). Then, they receive information about the type of displacement to be carried out:

- Hands position (hands on the thighs or hands on the hand rims).
- Spontaneous speed or maximum speed, then recording is initiated.

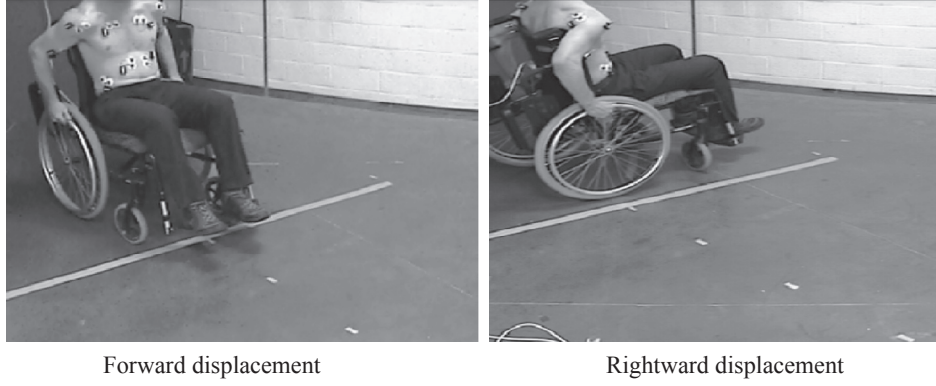


Fig. 1. Examples of two start conditions of subject displacement in manual wheelchair, hands on the hand rims condition.

2.3.3. Task

After a random period (minimum two seconds and maximum five seconds), a verbal start signal “GO” is given by the experimenter. The data recording is beginning before GO signal respecting the random period. The subject must then initiate its movement and make a displacement over a distance of 5 m. A total of 12 different displacements (two speeds * three directions * two hand's position) are made by each subject. Each condition was repeated three times, for a total of 36 displacements per subject (in a random order counterbalanced). Any test which is not carried out in accordance with the instructions is done again. Finally, only one repetition of each condition was retained for further analysis. The test selected is the one closest to the average test of the three repetitions.

2.4. Data analysis

All of the following treatments were performed on Matlab © R2016b (MathWorks Inc).

Level of muscle contraction. The determination of the muscular contraction level was carried out in three steps:

- High pass signal filtering at 35 Hz to remove much part of the artifact from ECG (Redfern et al., 1993; Hu et al., 2007). A small portion of the EMG signal is suppressed, but it is assumed that this information is recurrent on the other frequencies. The filter used is an IIR (Infinite Impulse Response) butterworth order 4 with forward backward process (to remove the phase shifts).
- Suppression of the sector artifact by a notch filter between 48 and 52 Hz (IIR butterworth order 8 with forward backward process).
- Rectification of the signal by computing the absolute value and application of a low pass filter at 12 Hz, in order to get an estimate of the instantaneous power (IIR butterworth order 4 with forward backward process).

The whole method was presented in the study by Clancy et al. (2002) and adapted to the specific requirements of the study. If it is more common to set the low-pass filter at lower frequencies. The realized choices for these setting provides better temporal accuracy at the expend of a more noised estimation of EMG instantaneous power.

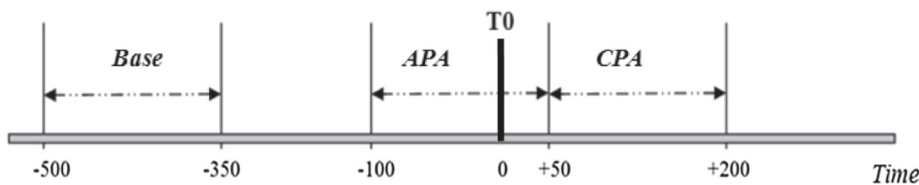


Fig. 2. Schema of temporal windows: basic (–500 to –350), APA (–100 to +50) and CPA (+50 to +200). APA anticipatory postural adjustment, CPA compensatory postural adjustment.

APA anticipatory postural adjustment, CPA compensatory postural adjustment.

Instants of onset. This instant is identified by a three-step procedure:

- Calculate of the derivative of the instantaneous power.
- The *onset* of muscle activation is fixed to a local maximum of this derivative. The first local maximum is taken whose value is greater than the threshold set at the 93th percentile of the signal. The percentiles allow a better adaptation to the current signal.
- The *onset* is validated after a visual check and manual correction if necessary (Approximately 10% of onset where corrected).

Relative intensity of APAs and CPAs. Measurements and comparisons of APAs and CPAs were carried out in four steps:

- Identification of the 'Prime mover' *onset*, the moment of the execution starts by the focal component. For this stage, during each test, the minimum onset of the activations of the focal component muscles were considered as the moment **T0** which allows the determination of the anticipation and compensation windows (Fig. 2).
- Calculate the EMG instantaneous power integrals during the windows of APAs and CPAs with respect to **T0**, during a time interval of 150 ms as shown in Fig. 2. (Santos et al., 2010; Claudino et al., 2013).

- APAs windows: –100 ms to +50 ms with respect to **T0**.
- CPAs windows: +50 ms to +200 ms with respect to **T0**.
- Base activity windows: –500 ms to –350 ms with respect to **T0** (Aruin et al., 1998).

- Correction or quantification (*Q*) of APAs and CPAs using the basic integral \int according to the following Eqs. (1) and (2):

$$Q_{APA} = \int_{-100}^{+50} APA - \int_{-500}^{-350} Base \quad (1)$$

$$Q_{CPA} = \int_{+50}^{+200} CPA - \int_{-500}^{-350} Base \quad (2)$$

- Inter-trial and inter-subject comparison of EMG activities.

In order to compare indices of EMG activity between the different

trials and across all subjects, all quantified integrals were normalized as follows: for each subject, and for each muscle separately, the maximum absolute values for the both windows (Q_{APA} and Q_{CPA}) were identified during all trials with the three directions (forward, right and left), with both speeds (spontaneous and maximum) and with both hand positions (hands on thighs and hands on the hand rims). This value is considered as the reference 'unit value'. All Q_{APA} values and Q_{CPA} values were divided by this 'unit value'. Thus, the values are included between 1 and -1. Positive values were associated with anticipatory activation and negative values with inhibition of anticipatory muscle activity (Kanekar et al., 2008).

2.5. Statistical analyses

After testing the distribution normality of the data by the Shapiro test, parametric tests (ANOVA with repeated measures and post hoc Tukey test) and nonparametric tests (Kolmogorov-Smirnov (2 conditions) and Kruskal Wallis (more than 2 Conditions)) have been carried out. The effect of hands positions, speed and directions, and the crossed effect speed * direction were tested. All the tests were carried out using software Statistica 10 (Statsoft ©). Statistical significance was set at $p < .05$.

3. Results

3.1. Effect of speed

Hands on hand rims. The relative intensities of APAs and CPAs are more important at maximum speed with compared to the spontaneous speed (Table 1):

- For APAs, these differences are significant at the level of the obliquus externus-right and obliquus externus-left ($p < .01$),
- For the CPAs, the speed has more influenced the following muscles: obliquus externus-right ($p < .01$), obliquus externus-left ($p < .025$), rectus abdominis-right ($p < .01$), rectus abdominis-left ($p < .005$), erector spinae-right ($p < .01$) and E erector spinae-left ($p < .05$).

Table 1

Effect of speed and direction of subject displacement in manual wheelchair on relative intensities of APAs and CPAs with hands on the thighs and hands on the hand rims conditions.

Variables	Muscles	Speed effect	Direction effect	S * D effect	Remarks
APAs HT	OE-R	< 0.005	0.29	< 0.01	RI > at MS & R (Ipsilateral side)
	OE-L	< 0.025	0.68	0.11	RI > at MS
	RA-R	< 0.05	0.16	0.17	RI > at MS
	RA-L	> 0.10	0.48	0.70	
	ES-R	> 0.10	0.53	0.25	RI > at MS & L (Contralateral side)
	ES-L	> 0.10	0.86	0.9	
APAs HH	OE-R	< 0.01	< 0.001	< 0.001	RI > at MS & L (Contralateral side)
	OE-L	< 0.01	< 0.05	< 0.01	RI > at MS & R (Contralateral side)
	RA-R	> 0.1	0.29	0.24	
	RA-L	> 0.1	0.69	0.82	
	ES-R	> 0.1	0.1	0.36	
	ES-L	> 0.1	0.18	0.09	
CPAs HT	OE-R	< 0.001	0.08	< 0.001	RI > at MS & R (Ipsilateral side)
	OE-L	< 0.001	0.23	< 0.01	RI > at MS & L (Ipsilateral side)
	RA-R	< 0.005	0.22	0.06	RI > at MS
	RA-L	< 0.05	0.41	0.22	RI > at MS
	ES-R	< 0.10	0.31	0.14	
	ES-L	> 0.10	0.68	0.83	
CPAs HH	OE-R	< 0.01	< 0.001	< 0.001	RI > at MS & L (Contralateral side)
	OE-L	< 0.025	< 0.001	< 0.001	RI > at MS & R (Contralateral side)
	RA-R	< 0.01	< 0.05	< 0.01	RI > at MS-F & L (Contralateral side)
	RA-L	< 0.005	0.54	< 0.05	without clear trend
	ES-R	< 0.01	0.11	0.065	RI > at MS
	ES-L	< 0.05	< 0.05	< 0.05	RI > at MS & L (Ipsilateral side)

The numbers show the p values. RA rectus abdominis, OE obliquus externus, ES erector spinae, SS spontaneous speed, MS maximum speed, F forward, R right, L left, HT hands on thighs, HH hands on handrails, RI relative intensity, APA anticipatory postural adjustment, CPA compensatory postural adjustment.

Hands on thighs. As observed for hands on hand rims, the relative intensities of APAs and CPAs are dependent on speed, with more relative intensity for the maximum speed (Fig. 3):

- For the relative intensities of APAs, these differences are significant at the obliquus externus-right, obliquus externus-left and rectus abdominis-right ($p < .005$, $p < .025$ and $p < .05$ respectively), more important at maximum speed compared to the spontaneous speed.
- Speed influences the relative intensities of the CPAs observed at the obliquus externus-right, obliquus externus-left, rectus abdominis-right and rectus abdominis-left ($p < .001$, $p < .001$, $p < .005$ and $p < .05$ respectively).

3.2. Effect of direction

Hands on hand rims. The results highlight the fact that the relative intensities of CPAs are more important than those of APAs (Figs. 3 and 4). For the obliquus externus, the relative intensities are more important on the contralateral side to the displacement, these are significantly different at the level of the obliquus externus-right to go to the left compared to the right or the forward direction ($p < .001$) (APAs and CPAs). It is the same for obliquus externus-left when displacement to the right compared to the forward condition during the APA period ($p < .025$) as well as for the left and forward direction for CPA ($p < .01$). The rectus abdominis-right is also activated with relative intensity on the contralateral side more important compared to the ipsilateral side of displacement ($p < .025$). The inverse is observed at the level of the E erector spinae-left, during the CPA, which activates more on the ipsilateral side.

Hands on thighs. For the obliquus externus, the relative intensities are more important on the ipsilateral side to the displacement. These tend to be different at the obliquus externus-left for the 'go left' condition compared to the 'go right' during the CPA period but with no significant difference. The inverse is observed at erector spinae level, which is more active on the contralateral side: at the erector spinae-right level for the CPA period, the relative intensity for a left displacement is more important than the relative intensity for forward or

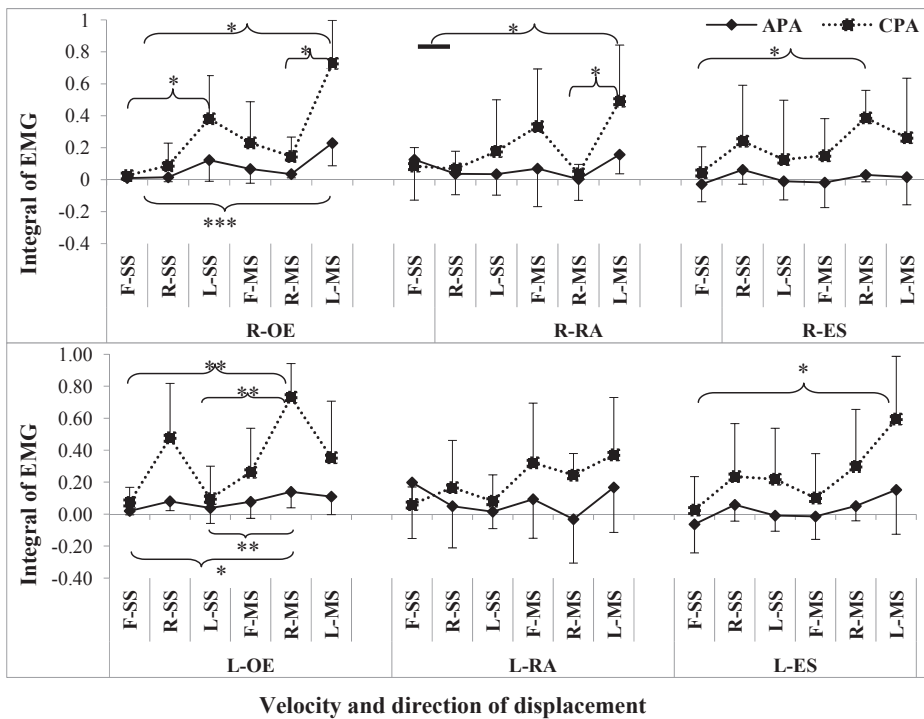


Fig. 3. Relative intensity of the APAs and the CPAs depending of the speed and the direction of movement of the subject displacement with hands on the hand rims condition. A brace means a difference between two conditions or between a condition and a set of conditions; a horizontal line means this set of conditions. RA rectus abdominis, OE obliquus externus, ES erector spinae, SS spontaneous speed, MS Maximum speed, F forward, R right, L left, APA anticipatory postural adjustment, CPA compensatory postural adjustment. Significant differences: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

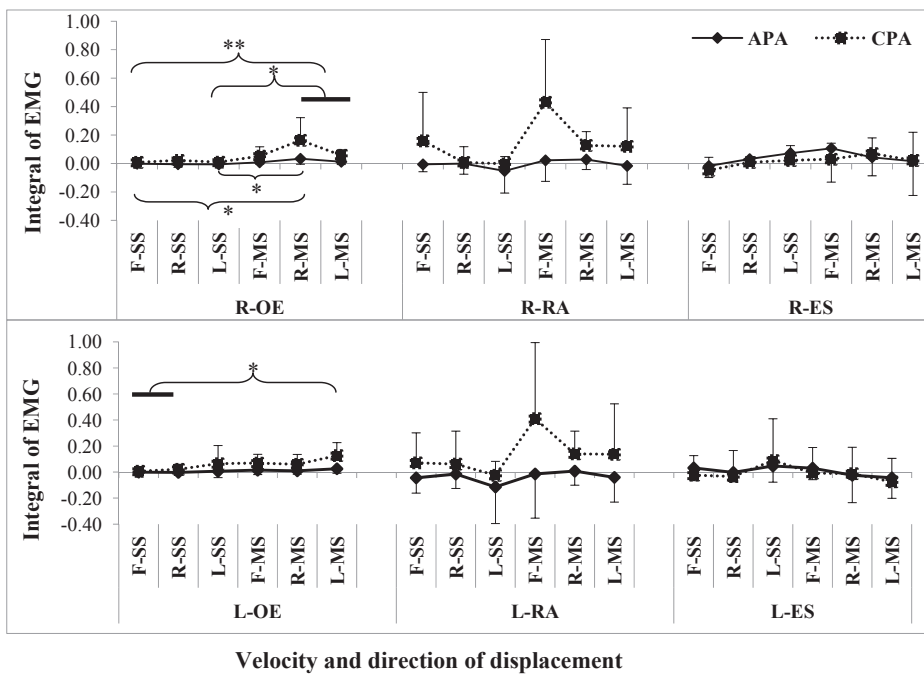


Fig. 4. Relative intensity of the APAs and the CPAs depending of the speed and the direction of movement of the subject displacement with hands on the thighs condition. A brace means a difference between two conditions or between a condition and a set of conditions; a horizontal line means this set of conditions. RA rectus abdominis, OE obliquus externus, ES erector spinae, SS spontaneous speed, MS Maximum speed, F forward, R right, L left, APA anticipatory postural adjustment, CPA compensatory postural adjustment. Significant differences: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

rightward displacement.

Relative intensities of APAs and CPAs are more important at maximum speed than spontaneous speed at the postural component in all conditions. Concerning the direction, the results depend on the initial condition of hands: For example, the obliquus externus is characterized by higher relative intensities on the contralateral side to the displacement in hands on the hand rims, however, an important relative intensity is found on the ipsilateral side at hands on the thighs conditions.

4. Discussion

The aim of this work is to study the arm-trunk coordination by

observing the APAs and CPAs. We hypothesized an adaptability of the muscular patterns to the different finalities of initiation of displacement in manual wheelchair in terms of speed and direction of the forthcoming displacement according to each hands position. The results obtained largely confirm the hypothesis.

Concerning the window of APAs, it was fixed between -100 and $+50$ ms with respect to T_0 . The 50 ms were taken after T_0 because the fastest monosynaptic reflexes can be observed, after a perturbation, in a time interval that is generally longer than 50 ms (Kanekar et al., 2008).

Application of the direction displacement of the subject in manual wheelchair requires specific arms movement. For example, the forward displacement is characterized by symmetrical propulsion of the two

arms. In contrast, turning left requires more propulsion by the right hand (contralateral side) than by the left hand (ipsilateral side). Therefore, the characteristics of the arm movements influence the perturbation induced and an adaptability of APAs as well as CPAs seems necessary and has been observed. Here, too, the results reinforce the idea of Slijper et al. (2002) that APAs are closely related to the direction of perturbation and therefore to displacement. The relative intensities of APAs and CPAs are also dependent on speed. Thus, more relative intensity is found with the maximum speed. The CNS shows a speed modulation strategy (Shiratori and Aruin, 2007) or speed sensitivity strategy (Gottlieb et al., 1989; Corcos et al., 1989). Moreover, these relative intensities of APAs and CPAs are adapted to the direction at the same speed, especially at the level of the obliquus externus: The CNS adapts the relative intensities according to the forthcoming speed and direction. The results show that the CNS uses a strategy of adaptability of motor commands at the postural level in relation to the speed (Horak et al., 1984; Lee et al., 1987; Shiratori and Aruin, 2007) and with the direction of perturbation (Aoki, 1991; Chabran et al., 1999; Shenoy and Aruin, 2007).

To plan a displacement, taking the example of gait initiation, Caderby et al. (2013), have questions about the effect of an additional load (15% of the body weight) on the control of APAs. They observed an increase in the duration of the APAs as well as of the impulse in the anteroposterior axis during the period of the APA. Another example, Ito et al. (2003), questions about the control of APAs during the gait initiation with two speeds: fast and spontaneous, and shows a significant increase in the relative intensities of the APAs for the fastest speed. These two examples emphasize that the CNS uses, as our results for the manual wheelchair seem to show, a strategy of adaptability of the motor commands when interacting with a simple object or according to the parameters of the forthcoming movement as speed.

Propulsion for initiation of displacement in manual wheelchair requires arm-trunk coordination to perform the task, maintain a postural balance and minimize effort. The arm-trunk coordination plays an important role in the success of the task by a spatiotemporal organization of the muscular patterns and kinematics of the joints (Lee et al., 2008). This coordination was observed by the simultaneous activation of the arm muscles, responsible for propulsion, and trunk muscles in forms of APAs and especially CPAs. The APAs and CPAs observed indicate the importance of the contribution of the trunk in the manual wheelchair propulsion (Yang et al., 2006). In addition, this arm-trunk coordination has shown adaptability to the displacement finalities in manual wheelchair. The muscular activities are adapted to speed and direction: The CNS constrains the relative intensities of the muscular activations. The trunk is adjusting, particularly during a forward displacement, to the forthcoming direction by a sway in the anteroposterior axis visible at the level of the relative intensities of the APAs and the CPAs similar at the rectus abdominis level. The trunk already leans forward to displace the CoM for a better subject-chair balance and optimize propulsion. The same trunk movement was observed in CPAs level. In contrast, to turn to the right or the left, at the level of the rectus abdominis and the obliquus externus, the relative intensities of the APAs and the CPAs are more important at the contralateral side to the displacement direction. This makes it possible to anticipate the rotation movement of the trunk toward the displacement direction. This study helps to better understand the arm-trunk coordination in initiation of displacement in manual wheelchair by measuring APAs and CPAs in the absence of disability. This study with able bodied subjects, is a necessary starting point for understanding the control of the initiation of displacement in manual wheelchair in homogeneous population with all locomotors capacity. Starting by studies with disable people is not possible, because: firstly, there is a dearth of literature on this topic: secondly, actual wheelchair users may have extremely diverse functional characteristics that make difficult to focus on a homogeneous population, especially if we focused on EMG activities; thirdly, we do not know the reorganization of the brain mapping in functional aspect that could

impaired the APA production, in relation with the specificity of the deficiency; fourthly, there is a lack in the literature to deal with the fact that the observed EMG activity is the results of predictive sign or consecutive to the deficiency. For these reasons, this starting study was design with able bodied subjects that allow to propose inference for disable people, that would be investigated by future studies. These first results can then serve as a reference for studying the effect of a deficiency (spinal cord injury, for example) on postural control in initiation of displacement in manual wheelchair. Several factors could influence the parameters of APAs and CPAs as trunk impaired users, head movements, seating, strapping. Investigate these differences with healthy able bodied subject could help to understand how the CNS solves this set of problems. It permits then, to investigate how the CNS control postural evolution especially considering “acquired” disability that need new sets of control, questioning motor control theory.

Limitations

Although this study has some highlights, there are certain limitations. The limit of the number of EMG channels did not allow the measurement of the muscular contraction of the entire postural component at trunk muscles. Thus, the role of the head has not been taken into consideration and understanding arm-head-trunk coordination remains necessary. Results are limited to the EMG data and segmental kinematics are also interesting for better understanding arm-trunk coordination. Finally, the study concerns a limited number of subjects, but in view of the many differences observed, the phenomenon highlighted could be more important than our significant differences show.

5. Conclusion

In the healthy subject, the CNS uses an adaptable motor control during initiation of displacement in manual wheelchair which we can highlight indirectly by EMG analysis and the observation of muscular patterns in accordance with the finalities of the forthcoming displacement in terms of speed (spontaneous speed vs. maximum speed) and direction (right vs. left vs. forward). Thus, all phases of movement (APA, CPA, postural component, focal component) appear to be defined by the CNS as a whole with a level of precision that is found in each phase of the movement. In the first step, it would be interesting to test the effect of standardization of the hands on the hand rims position. In the second step, these elements of control must be studied on a population of subjects presenting in particular a medullary injury, depriving the CNS of all the muscular chains possible to control the gesture.

The results obtained provide a fundamental insight into the strategies of arm-trunk control in terms of APAs and CPAs used by the CNS during initiation of displacement in manual wheelchair which can be recorded and thus potentially usable for a locomotive assistance system. Thus, at the application level, it would be interesting to complete the EMG data by adding other variables such as the center of pressure, in order to better predict the initiation of displacement in manual wheelchair and assist the user in a complex task in the presence of disability.

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Conflict of interest

The authors declared that there is no conflict of interest.

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