Influence of type of movement termination and sport practice on muscle activity during elbow extension movements.

Efecto del tipo de finalización del movimiento y práctica deportiva sobre la actividad muscular en el movimiento de extensión del codo.

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Abstract

Twenty participants were tested on rapid elbow extension movements. This experiment examined the effects of the type of termination (pointing vs. impact movements) and sport practice (karate vs. volleyball) on temporary specific electromyographic (EMG) and kinematic measures during elbow extension movements. EMG was recorded from triceps (main agonist) and biceps (main antagonist). The analysis of variance on the type of movement showed differences on the time from onset of EMG activation to peak EMG in agonist and antagonist when these variables are normalized to a proportion of total movement time. Also, correlation analysis showed strong correlations between the kinematic variables and the time from onset of EMG antagonist to peak EMG. This variable is the only EMG variable that presented differences in the analysis between sport groups. The results allow us to conclude that the delay in the biceps action expressed in the time from onset EMG activation to peak EMG normalized to a proportion of total movement time is an indicator of the performance level in fast movements.

Resumen

Veinte sujetos fueron evaluados durante la realización de rápidos movimientos de extensión del codo. En este trabajo se analizan los efectos que el tipo de finalización del movimiento (marcaje vs. golpeo) y el tipo de práctica deportiva (voleibol vs. kárate) tienen sobre variables específicas temporales de electromiografía (EMG) como de tipo cinemático. Se registró la actividad EMG del tríceps (principal músculo agonista) y del bíceps (principal músculo antagonista). El análisis de varianza acerca del tipo de movimiento mostró diferencias respecto al tiempo de comienzo de la activación EMG hasta el pico de actividad EMG del agonista y antagonista cuando esas variables eran normalizadas con respecto al tiempo total de movimiento. Además, el análisis de correlación realizado mostró correlaciones significativas entre las variables cinemáticas y el tiempo desde el comienzo de la actividad EMG del antagonista hasta su pico de actividad. Esta variable es la única considerada acerca de la actividad EMG que muestra diferencias en el análisis entre grupos. Los resultados nos han permitido concluir que el retraso en la acción del bíceps, expresado en el tiempo desde el comienzo de la activación EMG hasta su pico normalizado respecto al tiempo de movimiento, es un indicador del nivel de ejecución en un movimiento balístico como el utilizado en este estudio.

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Introduction

Fast movement of a single joint presents some kinematic and electromyographic characteristics, which define the central organization of the movement (Brown and Cooke, 1981). The analysis of the position, speed and acceleration curves shows the kinematic characteristics of a single joint movement. Several authors show the following kinematics characteristics in this kind of movements (Brown and Cooke, 1981; Latash, 1993; Ives et al., 1993; Milanovic et al., 2000; Gabriel, 2002): (i) the curve of position presents a sigmoid shape, (ii) the curve of speed presents a bell shape, and (iii) the curve of acceleration presents a double-peaked shape.

The EMG activity of a single-joint movement has been described by an important number of authors (Gottlieb et al. 1992; Latash, 1993; Ives et al., 1993; Pezarat-Correia et al.; Morrison and Anson, 1999; Schmidt and Lee, 1999; Milanovic et al., 2000, Prodoehl and Gottlieb, 2001, Almeida et al., 2006). These authors have observed that impact movement of a single joint show a biphasic or triphasic EMG pattern. The first event in the EMG is a burst of the agonist muscle, which will precede first detectable kinematic changes. Unless the movement is slow, the initial burst of the agonist is followed by a burst in the antagonist muscle. The antagonist burst is usually followed by a second burst in the agonist (Flanders, 2002). An increase in movement speed leads to a smaller delay in EMG events. In slow movements the antagonist activity disappears (Brown and Cooke, 1981). This triphasic pattern will be biphasic in very fast movements (Buchman et al., 2000) making the second agonist burst disappears.

The relation between the kinematic and electromyographic characteristics of the single-joint movements defines two ways of movement control. These two ways are known as dual strategy hypothesis (Gottlieb et al., 1992; Corcos et al., 1996; Gielen et al., 1998; Massion, 2000). The first is called *speed-insensitive strategy*, and it appears when the movements made over different distances and against different inertial loads and have no constraint on movement time. These movements are performed by prolonging the duration of excitation to motoneuron pools and delaying the onset of antagonist muscle activation (Corcos et al., 1996). Latash (1993) expounds the following rules for the Speed-Insensitive Strategy: (1) intensity of the agonist excitation pulse is constant and duration is modified, (2) EMG rises initially at the same rate irrespective of movement distance and load, (3) joint torque rises initially at the same rate, and (4) two excitation pulses are proposed for the antagonist. The first one defines initial "coactivation" phase of antagonist EMG, while the second generates the antagonist burst.

The agonist-antagonist coordination is one of the main information sources about voluntary movements. In single joint movements, this influence is more important. There are studies about how the sequence of activation of the agonist-antagonist binomial defines the movement of joint characteristics (Brown and Cooke, 1981; Gottlieb et al., 1992; Pezarat-Correia et al., 1996; Morrison and Anson, 1999; Welter and Bobbert, 2002, Raikova et al., 2005).

Two objectives are proposed in our study. On the one hand, we were interested in how myoelectric and kinematic variables changed as a function of the type of termination. The influence of the type of termination in single joint movements has been studied by several authors (Brown and Cooke, 1981; Gottlieb et al., 1992; Pezarat-Correia et al., 1996; Morrison and Anson, 1999; Gottlieb, 2000; Gottlieb, 2001). Brown and Cooke (1981) found

that the triphasic pattern that characterizes the single joint movements is usually found in fast movements rather than in slow ones. In slow movements, antagonist burst is slow or absent, while the level of coactivation of agonist and antagonist muscles increases in explosive movements. Gottlieb et al. (1992) showed that the type of termination defines EMG patterns. When the subjects need to adjust movement time, there are differences in the intensity of the excitation pulse. When there are no constraints on movement time, differences appear on duration pulse.

The second variable to study was the influence that previous experience of the subjets could have on the kinematics and EMG variables. Schneider, Zernicke, Schmidt and Hart (1989) studied the modifications on neuromuscular patterns with the learning of a motor skill. These authors showed that with practice, motor coordination was modified. After practicing, the movements are made with lower levels of coactivation. Zehr and Sale (1994) showed that high-velocity ballistic training induces specific neuromuscular adaptations that occur as a function of the underlying neurophysiological mechanisms that subserve ballistic movement. Therefore, Morrison and Anson (1999) found that, with practice, the timing of several EMG variables was altered. Therefore, the occurrence of the EMG pattern in single joint movements can be influenced by the amount of practice. Zehr, Sale and Dowling (1997) studied the differences in ballistic movements between karate athletes and untrained men. These authors obtained differences in kinematic variables, but there were no group differences in EMG pattern.

Finally, the aims of this study are to determine the influence of the type of termination and the influence of previous training in the performance of a single joint movement.

Method

Participants

Twenty healthy participants, aged 16-35, participated in this study after giving informed consent. Ten were Spanish First Division volleyball players, and ten were National Level karate athletes. The participants were questioned to determine their dominant hand. The characteristics of volunteered participants are shown in Table 1.

Table 1. Mean ± standard deviation of age, weight, height, and moment of inertia for the forearm for all participants.

	N	Age (years)	Weight (kg)	Height (cm)	Moment of inertia forearm (kg · cm^2)
Karate	10	21,27 ± 3,69	79,00 ± 8,22	178,45 ± 4,10	66,74 ± 7,71
Volleyball	10	25,18 ± 5,23	83,59 ± 7,34	183,90 ± 4,72	72,72 ± 7,31
Total	20	23,23 ± 4,85	81,29 ± 7,96	181,18 ± 5,14	69,73 ± 7,94

Apparatus

A target 30 cm in diameter was positioned to 140º of the elbow angle. A 3D motion tracking Polhemus Fastrack™ was attached to the anterior surface of the wrist, medial to the styloid of the radius. The EMG was collected with Physiological Data System J&J (model I–410), with surface electrodes Beckam Ag/AgCl, one centimetre of diameter. The signal was amplified at a range of 1/5000 mv, and was collected with a root mean square filter. Prior to application, the electrical impedance of the skin at each site of electrode placement was minimized using standard skin preparation procedures (Basmajian and Blumenstein, 1980). The electrodes were placed over the belly of biceps and lateral head of the triceps, following Zipp´s procedure (1982). The distance between electrodes was 1 centimetre in line with the muscular fibres (Basmajian and De Luca, 1985). On the other hand, the mass electrode was positioned over the acromion in order to keep it away from the electrodes of measurement and in a neutral point to the voltage of body, such as in a bone zone (Basmajian and De Luca, 1985).

Procedure

Participants were seated comfortably in a chair and placed their upper dominant arm on a horizontal surface so that the shoulder joint was flexed 90º. The arm was supported just distal to the elbow, and the shoulder was fixed to the chair. They performed 20 trials of elbow extension movements to a target. From starting position 50º (180º being the full elbow extension), the participants performed elbow extension movements over the angular distance of 140º, corresponding to 90º of the elbow angle. Figure 1 shows the position of the participants before and after the elbow extension movement.
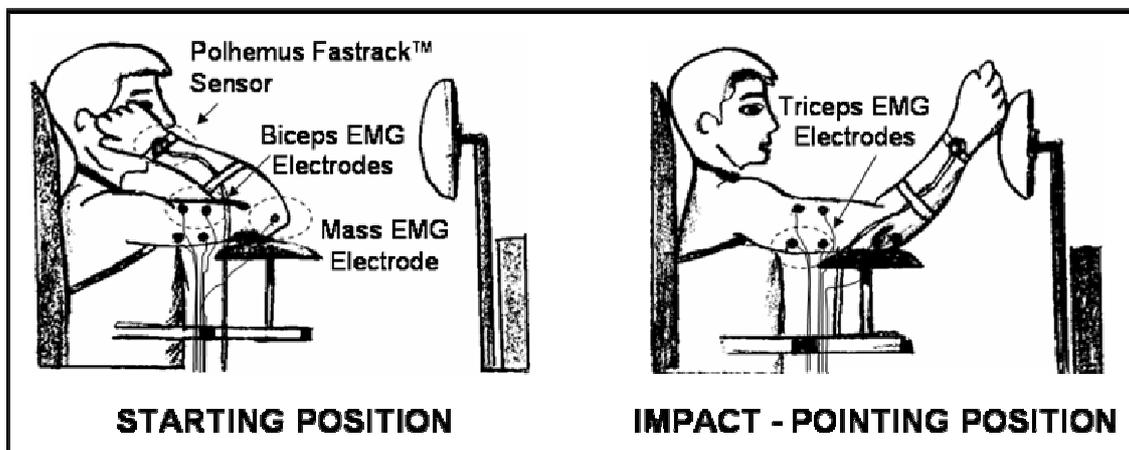

Figure 1. Position of the participants before and after the elbow extension movement.

The participants performed 10 trials (Ervilha and Arendt-Nielsen, 2004) in two movement conditions (impact and pointing movements), and trials of different instructions were executed with a random order. The instructions to the participants were: (i) "punch the target as quickly as possible", and (ii) "move your fist to the target as quickly and accurately as possible. Do not transmit force to the target". The time interval between two consecutive trials was 45 seconds. The participants never performed the tasks with fatigue.
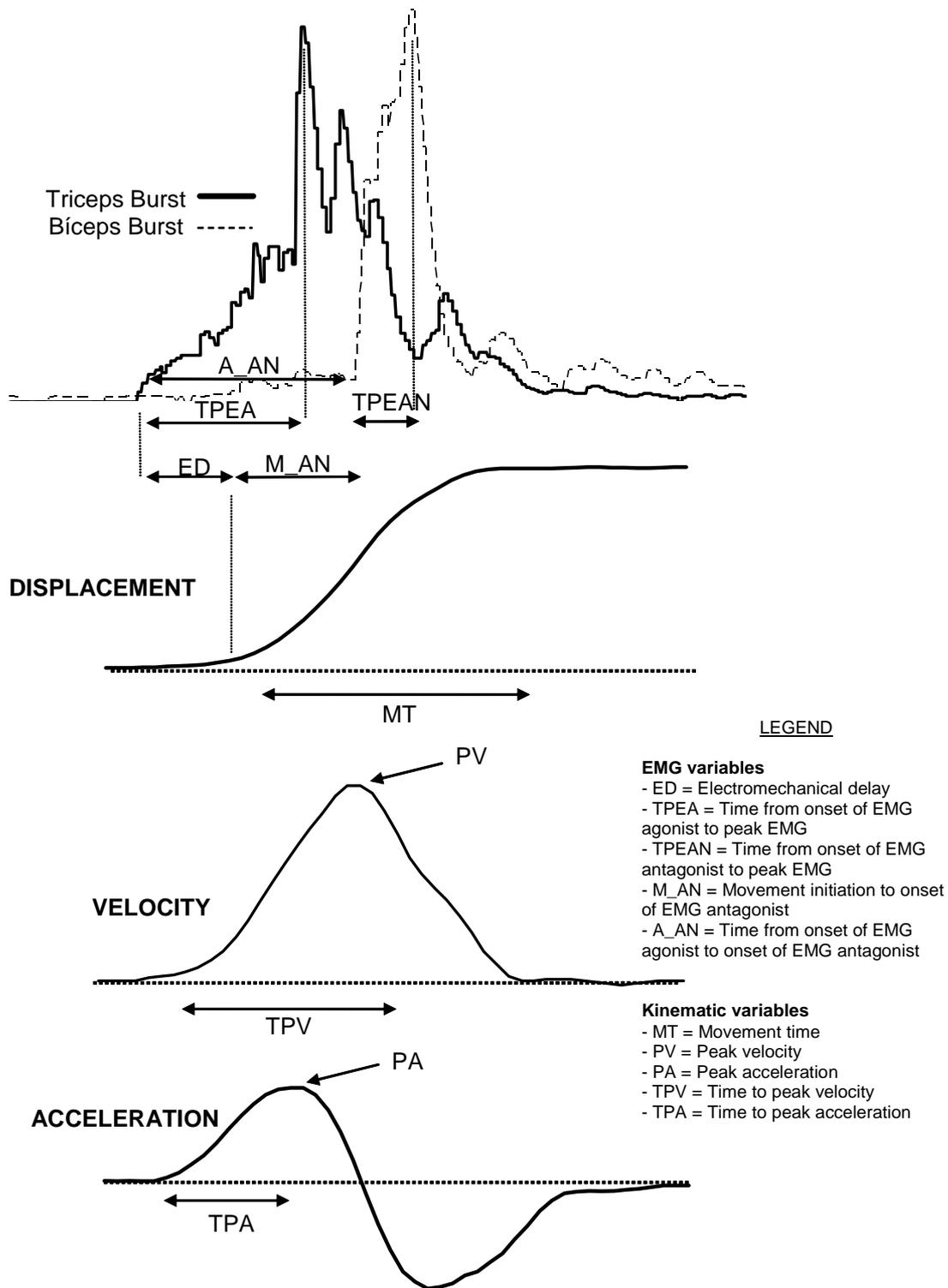
Figure 2. Kinematic and EMG variables

The description of a triphasic pattern of single joint movement is distinguished by its temporal characteristics (Morrison and Anson, 1999). Therefore, the dependent variables in

our study were: (i) Movement time (MT), (ii) Peak velocity (PV), (iii) Peak acceleration (PA), (iv) Time to peak velocity (TPV), (v) Time to peak acceleration (TPA), (vi) Electromechanical delay (ED), (vii) Time from onset of EMG agonist to peak EMG (TPEA), (viii) Time from onset of EMG antagonist to peak EMG (TPEAN), (ix) Movement initiation to onset of EMG antagonist (M_AN), and (x) Time from onset of EMG agonist to onset of EMG antagonist (A_AN). All variables are phrased in milliseconds (ms), except for maximal velocity and maximal acceleration that will be phrased in grades per seconds and grades per seconds with squares, respectively. The onset of EMG was placed when the muscle activity exceeded the double the standard deviation range of the baseline in the first 300 ms. Figure 2 shows a graphic with EMG and kinematic variables.

To control for the altered timing of activity, the EMG variables were also normalized to a proportion of total movement time (ED_{normt}, $TPEA_{normt}$, $TPEAN_{normt}$, M_AN_{normt}, A_AN_{normt}) (Flanders and Herrmann, 1992).

The independent variables were the instructions given to the participants (pointing and impact movements) and the group (volleyball and karate).

Results

Figure 3 shows examples of EMG pattern activity in karate athletes and volleyball players associated with different instructions. Differences observed between EMG patterns in impact and pointing movements are characteristic from karate group.

An analysis of variance (ANOVA) was made between the groups in impact and pointing movement condition. Table 2 shows the outstanding variables with significant differences. The karate group showed better kinematics scores than volleyball players in impact task. There were no significant differences in the MT variable, although the mean values differ from one group to another, showing that the volleyball group performed higher values (439 ms) than the karate group (306 ms). Also, the volleyball players needed more time to reach the electric activity for the agonist and antagonist muscles.

Table 2. Variables with significant differences for ANOVA made between the groups in impact and pointing movement conditions.

	Volleyball			Karate			$F_{1,19}$	*p.*
	M	±	*SD*	*M*	±	*SD*		
	Impact Movement Condition							
PV	374,88	±	91,20	500,52	±	124,08	6,885	0,017
PA	28,92	±	9,00	44,28	±	12,36	10,411	0,004
$TPEA_{normt}$	-9,43	±	18,60	28,25	±	30,91	10,910	0,004
$TPEAN_{normt}$	25,97	±	13,15	54,68	±	23,48	11,383	0,003
	Pointing Movement Condition							
PA	26,40	±	7,80	37,08	±	12,00	4,864	0,041
$TPEA_{normt}$	-11,72	±	14,58	17,11	±	18,54	12,895	0,002
$TPEAN_{normt}$	19,74	±	16,07	46,11	±	12,65	15,234	0,001

Something similar happens with the values in this pointing task, showing differences in the peak acceleration value and the time employed to reach the peak of muscle electric activity. The mean values of MT and PV could be pointed out, although without significant differences. Therefore, the karate group shows values of 336 ms and 448,53 º/s for the MT and the PV respectively. On the other hand, the volleyball group performed scores of 411 ms and 351,60º/s.

A Pearson correlation analysis was also conducted to analyze possible interactions among the studied variables. Significant correlations were obtained for all kinematics variables with $TPEAN_{normt}$. Also, there were another significant correlation between the $TPEA_{normt}$ and the peak of velocity. Table 3 shows the correlations for the trials in the impact task, considering the mean values of both groups. However, Table 4 shows the correlation for the trials in the pointing task. In this task, the same correlations were obtained.

Table 3. Pearson correlation analysis for impact movement condition.

	MT	PV	PA	ED	$TPEA_{normt}$	$TPEAN_{normt}$
MT		-0,850**	-0,829**	-0,601**	-0,243	-0,573**
PV	-0,850**		0,980**	0,385	0,446*	0,732**
PA	-0,829**	0,980**		0,313	0,439	0,710**
ED	-0,601**	0,385	0,313		-0,753**	-0,729**
$TPEA_{normt}$	-0,243	0,446*	0,439	-0,753**		0,807**
$TPEAN_{normt}$	-0,573**	0,732**	0,710**	-0,729**	0,807**	

$* \ p < 0,05; ** \ p < 0,01$

Table 4. Pearson correlation analysis for pointing movement condition.

	MT	PV	PA	ED	$TPEA_{normt}$	$TPEAN_{normt}$
MT		-0,847**	-0,827**	-0,230	-0,444	-0,586*
PV	-0,847**		-0,957**	0,199	0,446*	0,732**
PA	-0,827**	-0,957**		0,140	0,447	0,551*
ED	-0,230	0,199	0,140		-0,527*	-0,514*
$TPEA_{normt}$	-0,444	0,446*	0,447	-0,527*		0,800**
$TPEAN_{normt}$	-0,586*	0,732**	0,551*	-0,514*	0,800**	

$* \ p < 0,05; ** \ p < 0,01$

The third analysis carried out was a repeated measures ANOVA for the movement type variable (impact and pointing). Firstly, this analysis was carried out for all participants, in order to infer the effects of the independent variables on the each dependent one. Table 5 shows the variables with significant differences between the impact and the pointing task, also the mean and the standard deviations values of these variables is showed. Significant differences for all kinematics variables can be observed. A difference for the electromyography variable was also obtained ($TPEAN_{normt}$). The same repeated measures

ANOVA analysis was carried out for each group. Significant differences were obtained for the volleyball group in the kinematic variables PV ($F_{1,18}$ = 12.576; p<0,01) and PA ($F_{1,18}$ = 34,821; p<0,01). The PV mean values were 354,36±95,4 °/sec in the pointing trials, and 381,36±91,2 °/sec for the impact ones. The PA mean values were 26,16±8,52 °/sec^2 in the pointing trials, and 29,4±8,04 °/sec^2 for the impact ones. Finally, Table 6 shows the variables with significant differences for the karate group. It can be observed that this group had significant differences for all kinematics variables among the impact and pointing tasks. The differences in the variables TPEA$_{normt}$ y TPEAN$_{normt}$ among the two tasks could also be pointed out.

Table 5. Variables with significant differences for repeated measures ANOVA for the movement type in both groups.

	Pointing Condition			Impact Condition			$F_{1,18}$	$p.$
	N	M	$\pm$ sd	N	M	$\pm$ sd		
MT	135	338,00	$\pm$ 86,00	135	318,00	$\pm$ 103,00	7,61	0,007
PV	138	430,80	$\pm$ 111,96	138	466,56	$\pm$ 121,10	50,44	0,001
PA	111	34,80	$\pm$ 11,28	111	40,44	$\pm$ 12,60	95,13	0,001
TPV	138	149,00	$\pm$ 74,00	138	113,00	$\pm$ 39,00	34,91	0,001
TPA	110	47,00	$\pm$ 35,00	110	37,00	$\pm$ 22,00	5,48	0,021
TPEAN$_{normt}$	114	37,41	$\pm$ 27,81	114	48,31	$\pm$ 36,32	7,85	0,006

Table 6. Variables with significant differences for repeated measures ANOVA for the movement type in karate group.

	Pointing Condition			Impact Condition			$F_{1,18}$	$p.$
	N	M	$\pm$ sd	N	M	$\pm$ sd		
MT	78	310,00	$\pm$ 76,00	78	281,00	$\pm$ 94,00	12,62	0,001
PV	78	489,60	$\pm$ 85,44	78	532,20	$\pm$ 98,40	45,84	0,001
PA	63	41,28	$\pm$ 8,40	63	48,12	$\pm$ 9,84	68,18	0,001
TPV	77	123,00	$\pm$ 38,00	77	101,00	$\pm$ 31,00	17,39	0,001
TPA	63	5300	$\pm$ 30,00	63	41,00	$\pm$ 25,00	7,85	0,007
TPEA$_{normt}$	65	20,91	$\pm$ 28,53	65	33,03	$\pm$ 42,67	5,35	0,024
TPEAN$_{normt}$	65	48,66	$\pm$ 24,30	65	65,14	$\pm$ 34,97	9,80	0,003

Discussion

Kilmer, Kroll and Congdon (1982) suggested that duration and latency of EMG burst play an important role in fast movements. We proposed that changes in the magnitude and duration of muscle activity could be used to determine the kinematics characteristics of a single joint movement. The bursts of EMG activity and overlapping of agonist and antagonist muscle may exhibit the level of performance of a motor pattern (Raikova et al., 2005). So, when a new movement is learned, shows an overlapping activity of agonist and

antagonist, while a learned movement shows alternative bursts of agonist and antagonist (Gribble et al., 2003). That overlapping is knowed as coactivation, and implies a higher energy cost in the movement (Dorado, 1996; Seidler-Dorbin et al., 1998).

We can state that the EMG analysis would reveal differences on agonist-antagonist coactivation patterns between both groups of athletes, and these differences imply different kinematic patterns. These conclusions are different regarding the findings of Zehr, Sale and Dowling (1997) in a similar study. We have found that the karate group performed both tasks (impact and pointing movements) in a different way, with two patterns clearly defined. However, the volleyball group showed similar EMG patterns in both tasks. The difference between both groups can be found on agonist-antagonist coactivation. The karate group adjusts antagonist activity on pointing movements and impact ones because with practice, there was a decrease in the amount of cocontraction between the agonist and antagonist muscles during movement execution (Moore and Marteniuk, 1986, Gribble et al., 2003). Volleyball players have not learned pointing movements so they do not control antagonist muscle with higher levels of coactivation (Figure 3).

The ANOVA between the two groups on pointing and impact movements have shown differences on the PA variable. Karate athletes show larger acceleration peaks, and can provoke higher levels of strength than volleyball players. These differences on kinematic variables are related with EMG variables as $TPEA_{normt}$ and $TPEAN_{normt}$. Several authors have studied the EMG patterns during single joint movements when there are no explicit or implicit constraints on movement time, termed speed insensitive strategy (Gottlieb et al., 1992, Corcos et al., 1996). On these movements, the intensity of the agonist excitation pulse is constant and duration is modified. This is because we have adopted time from onset of EMG to peak as a variable that describes the latency of muscles involved in movement and, therefore, a parameter controlled by central programs according to the requirements of the task (Gottlieb, 2001).

In impact and pointing movements, the karate group showed delayed peaks on EMG burst both in agonist and antagonist muscles. The delay on agonist maximal activity could be a variable that best explains values on kinematic variables. Increasing the duration of the agonist muscle EMG burst increases the acceleration of the movement. As a result, karate athletes showed longer duration of acceleration and higher values on PV, PA and lower ones on MT. These results are differents to the study of Zehr, Sale and Dowling (1997). These authors obtained differences in PA between karate athletes and untrainded men in ballistic movements, but there were not differences in PV and MT. Otherwise, differences found on $TPEAN_{normt}$ with larger values in the karate group lead us to suggest that this group have learned to delay the antagonist activity. This delay on antagonist EMG burst implies the decrease of MT (caused by the delay of the movement braking) increasing the duration of acceleration and velocity of the movement (Pezarat-Correia *et al.*, 1996). The relations observed go beyond the findings of Jaric, Ropret, Kukolj and Illic (1995), suggesting that an appropriate training of the antagonist muscles will improve fast movements performance due to a shorter deceleration.
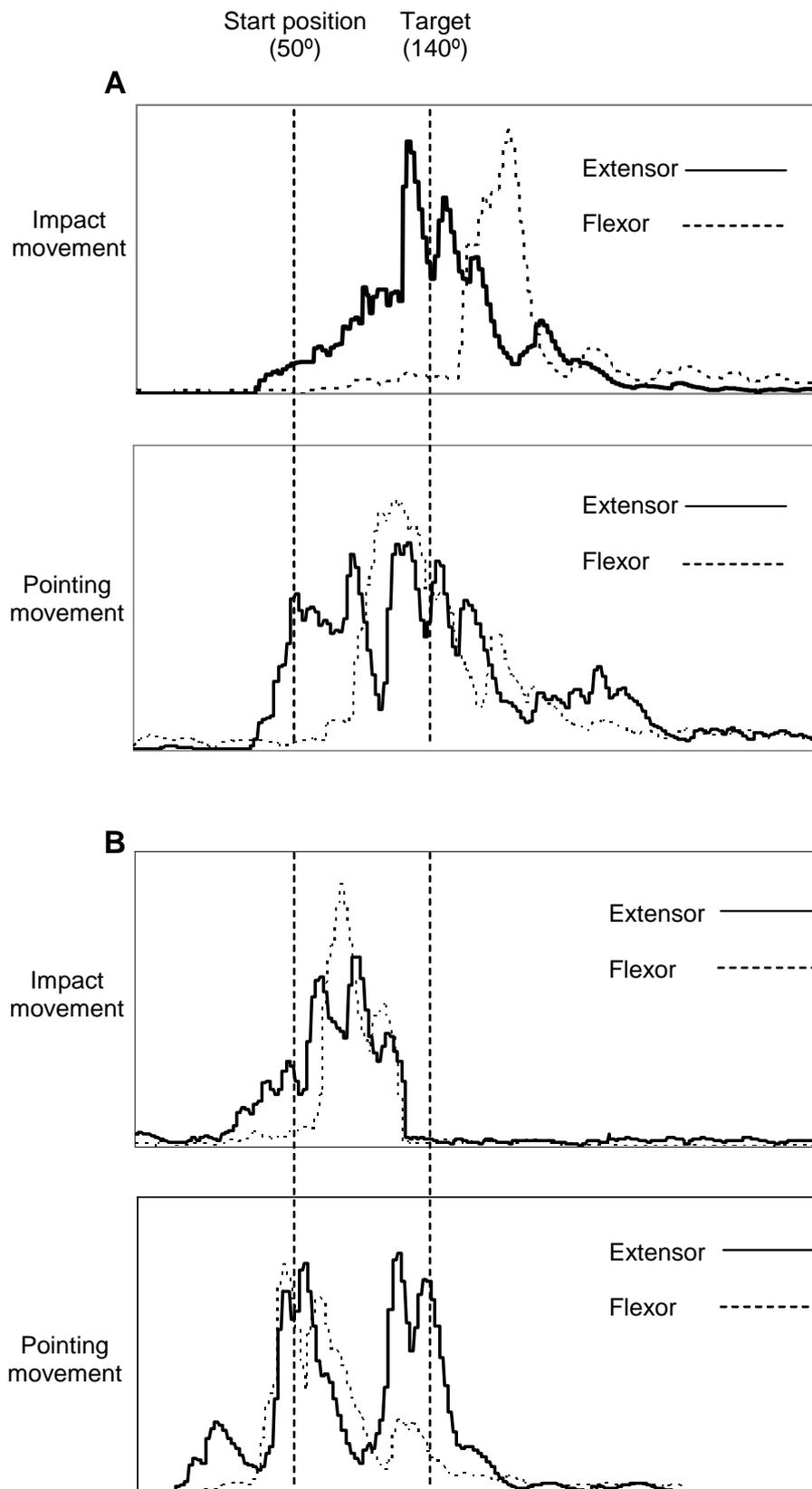
Figure 3. Example of EMG pattern activity in karate athletes (A) and volleyball players (B) associated with different instructions. Two different EMG pattern for different tasks are observed for karate athletes while higher level of co-activation is observed in both tasks for volleyball players.

It must be noted that MT is shorter, as said above, even in pointing movements for the karate group, so the delay on antagonist activity may be the reason for differences between both groups. This conclusion is supported by the significant correlations between kinematics variables and $TPEAN_{normt}$. From this correlation, it may be concluded that a delayed antagonist activity could be related with a lower MT (Suzuki and Shiller, 2001). Accordingly, Seidler-Dorbin and Stelmach (1998), and Gottlieb (2000), suggest that coactivation (as anticipated antagonist activation) impede the segments to accelerate as quickly as possible.

The overall repeated measures ANOVA showed significant differences in kinematic variables. Impact movements showed shorter MT and larger values in PV and PA than pointing movements. This confirms that an impact movement is faster than a pointing one, as many other studies have suggested earlier (Brown and Cooke, 1981, Gottlieb et al., 1992, Gottlieb, 2001). Morrison and Anson (1999) suggest that manipulating task constrains and practice, temporal characteristics of triphasic EMG should be changed. $TPEAN_{normt}$ is longer in impact movements, so maximal antagonist activity is released earlier in pointing movements. This relationship goes beyond the reports of Gottlieb et al. (1992) about brake function of the antagonist muscles, which allow larger values of velocity and acceleration, and shorter MT, delaying their activation in impact movements.

The volleyball group did not show differences between impact and pointing movements neither in MT nor in any other EMG variables. It should be suggested that their pattern is very similar for both kind of movements, perhaps because in their learning process there was no differentiation in practice. Hallet, Sahani and Young (1975) found that the triphasic pattern in fast elbow movements is centrally programmed. Nevertheless, the findings from this study have shown that the volleyball group uses the same motor program for both impact and pointing movements. This may be the reason to find differences in PV or PA (kinematics) but not in EMG variables which define muscle pattern.

However, the karate group showed differences between impact and pointing movements in kinematic variables and in $TPEAN_{normt}$. Impact movements showed shorter MT and larger PV and PA than pointing movements. As we said above, these differences were foreseeable (Brown and Cooke, 1981; Gottlieb et al., 1992). $TPEAN_{normt}$ is significantly different between the two types of movements, suggesting that in pointing movements the antagonist activation (brake role) emerge earlier than in impact ones. The repeated measures ANOVA also showed differences in $TPEA_{normt}$, with larger values in impact movements than in pointing ones. This leads us to believe that a higher interval in which agonist is activated it will improve the efficiency of the movement.

Conclussions

Two conclusions should be extracted from this study. First, learning processes carried out by the karate group, training differentiated pointing and impact movements lead them to acquire two motor patterns. This is reflected in kinematic advantages over the volleyball group in impact movements but especially in pointing movements. Second, relative time to peak of antagonist EMG activity have shown as an interesting variable to assess the performance level in fast and accurate movements.

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