THE EFFECT OF WALKING SPEED AND SKILL LEVELS ON ELBOW FLEXION AND UPPER LIMB EMG SIGNALS IN NORDIC WALKING: A PILOT STUDY

Nicola Petrone[1], Manuel Orsetti[1] and Giuseppe Marcolin[2]

Department of Mechanical Engineering University of Padova, Italy [1]
Department of Anatomy and Physiology University of Padova, Italy [2]

Aims of the study were to evaluate the effect of the walking speed on the elbow's range of motion and the EMG activity levels on eight upper limb muscles when performing level Nordic Walking in outdoor sessions. The study involved both skilled Nordic Walking instructors and unskilled beginners to highlight the effect of a correct technical execution on the elbow's flexion angle and the EMG signals. All the subjects performed also level walking tests without poles at the same speeds of the NW tests: the EMG activation levels during walking were taken as control values of each subject to estimate the additional activation due to the poles.

KEY WORDS: Nordic Walking, EMG, elbow flexion-extension angle, walking speed, skill.

INTRODUCTION: Nordic Walking is becoming a popular physical activity due to its claimed advantages on the musculoskeletal and cardiovascular systems related to higher values of upper limb biomechanical involvement and full body energy consumption.

Despite its popularity, there are several publications focusing on lower limb biomechanics (Schwameder 1999, Willson 2001) or on the physiological effects on the full body (Schiffer 2006) but few works focused on the upper limb biomechanics and in particular on the EMG activation patterns of Nordic Walking (NW) compared to normal walking (W) in standard conditions.
In the present work, a protocol for the comparative evaluation of Expert and Beginner subjects walking with or without poles at different speeds was defined and applied to a small number of subjects in order to orient further wider works.

METHODS: Participants: Four subjects were involved in the study: two were National Instructors from the Italian Nordic Walking Association (ANWI) and two were students at the Exercise Science Faculty that had never performed NW and received a short verbal lesson about the NW technique before the tests. All subjects signed an informed consent before the tests.

Table 1 Data about the subjects involved in the study.

Subject	ID	Age	Height [cm]	Mass [kg]	Skilll	Pole length [mm]	Vmax [km/h]
E1	OM	28	170	77	Expert	1150	8,50
E2	ZL	42	180	68	Expert	1200	8,60
B3	GM	31	186	78	Beginner	1250	8,40
B4	ND	23	186	85	Beginner	1250	8,80

Data Collection: The research protocol was based on the possibility of recording outdoor the EMG signals on eight muscles together with the elbow flexion angle at controlled walking speeds. In order to account for the specificity of each subject's anthropometry, gender, skill and training state, the test speeds were referred not to absolute speed values but relative to the maximum sustainable walking speed selected by each subject in a pre-test with poles.
Data of each test trial were recorded by means of a 16 channels PocketEMG (BTS-Italy) portable PC placed on the back of the subject (145x95x20mm, mass 0.3kg). Eight channels were used to collect EMG data with bipolar surface electrodes placed on the muscle bellies at a distance between electrodes of 25mm. The reference electrode was applied on C7. The eight muscles involved in the measure were: triceps brachii caput longus (TBCL); deltoideus posterior (DP); latissimus dorsi (LD); pectoralis major sternal head (PECMSH); trapezius

transversalis (TRM), trapezio ascendens (TRS); obliquus externus abdominis (OEA); erector spinae (ERSL).

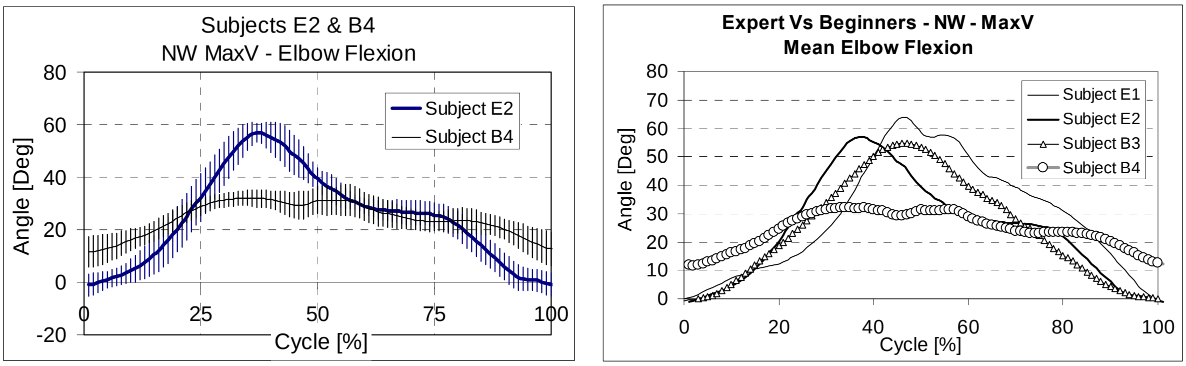
A Biometrics® goniometer was placed on the left elbow, and zeroed at fully extended arm: all data were synchronously recorded at 1Khz. A wrist Global Positioning System (GPS) Garmin Forerunner305® was used to measure the speed of each subject during each trial: to avoid any influence on the correct execution of walking, a second operator following closely the subject under test was reading the speed on the GPS and giving instructions for maintaining the walking speed at the preset value. Each trial was filmed with a commercial digital camera at 25Hz from the right side.

The tests were performed in summer on grass surface of a city park in Padova at sea level: a track of 60 m length was marked with cones and covered in the two directions for each speed: in a pre-test the maximum sustainable speed with poles $\mathbf{v_{pmax}}$ was selected by each subject. Then, for each trial, the track was walked in one way to familiarize with the speed: on the way back the recording was started. After the forward-backward trial with the poles, the subjects performed at the same speed a trial without poles, again recording the data on the way back. These trials were then performed at 80% of the maximum walking speed $\mathbf{v_{pmax}}$ and finally at 60% of the $\mathbf{v_{pmax}}$. Eventually, still wearing the data acquisition system, the subjects performed their isometric Maximal Voluntary Contractions (MVCs) on restraint frames helped by operators.

Data Analysis: Analysis of trials focused only on the way back on the track and, in particular, on the last 30 m of the 60 m track length, to avoid speed settling of initial strides. The electrogoniometer signal at the elbow was used to define the gait cycle as the interval between two consecutive minimum values of the elbow flexion angles.

EMG raw signals of the eight muscles were first rectified, then integrated with a mobile window of 200ms, filtered with a 5Hz low pass Butterworth filter and finally normalized with respect to the Maximal Voluntary Contractions (MVCs) and to the cycle length. The final step after the time normalization was to average 10-15 strides performed in the last 30 m of the track to obtain the mean curves of the different analyzed values (Figure 1.a).

To evaluate the specific effect of using the NW poles, the difference between the peak EMG signal of trials performed with poles (NW) and the peak EMG signal of trials without poles (W) was calculated and used to estimate the increment in muscle activation due to the Nordic Walking with respect to normal Walking: this was named ΔEMG_{MUSCLE} and expressed as %MVC.



(a) (b)

Figure 1: (a) Elbow flexion mean angles from 14 consecutive strides with SD band from E2 and B4. (b) Mean elbow flexion curves from the four subjects during Nordic Walking at maximum speed.

RESULTS: Mean curves of elbow flexion at maximum speed in Nordic Walking from the four subjects are presented in Figure 1.b: an initial evaluation of video and elbow flexion data performed in accordance with NW instructors induced the authors of the present pilot study to focus further comparisons on subjects E2 and B4. In fact, subject E2 was preferred to E1 for his smoother technique, whereas B4 was preferred to B3 due to the surprisingly positive response to verbal lesson of the latter. The elbow flexion mean curves from E2 showed similar peak values with increasing speed, whereas a significant decrease of peak flexion angle and flexion Range of Motion (R.O.M.) at increasing speed were found for subject B4 (Figure 2).

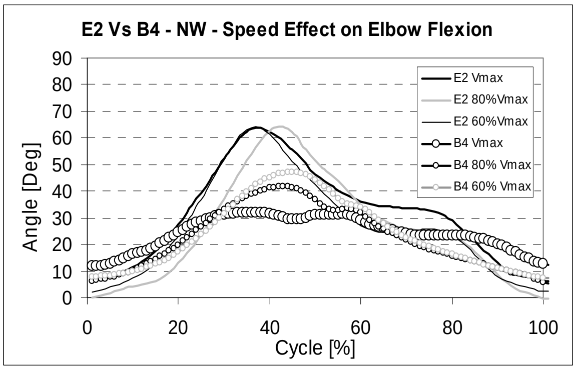


Figure 2. Comparison of the Elbow Flexion between Expert (E2) and Beginner (B4) at different Nordic Walking speeds.

The normalized signals of EMG at the TBCL muscle from expert subject E2 when walking without poles (W) showed specific patterns with lower EMG peaks than walking with poles (NW) (Figure 3). This appeared consistently in the other muscles and justified the introduction of ΔEMG_{MUSCLE} in the data analysis. The walking speed effect on EMG signals was less evident in the expert subject E2 compared to beginner B4 for the TBCL muscle (Figure 4), as well as for other most activated muscles. Peak EMG values for all the measured muscles of two representative subjects E2 and B4 are reported in terms of percentage of MVC in Table 2 together with the corresponding ΔEMG_{MUSCLE} values expressing increments of NW relative to W.

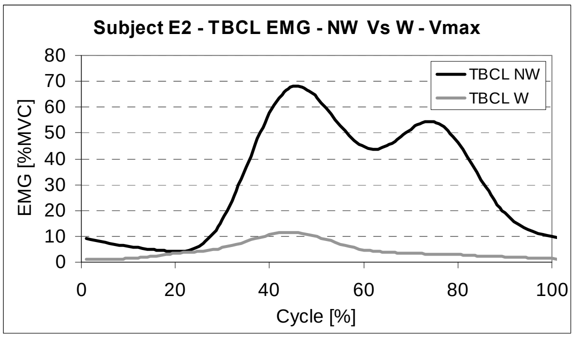
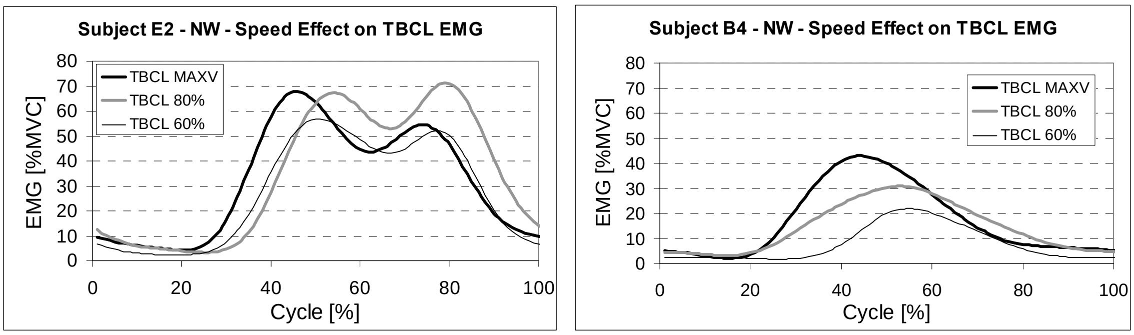


Figure 3: Comparison of the TBCL normalized EMG signal between Nordic Walking and Walking for expert subject E2 at maximum speed.

DISCUSSION: The aim of the pilot study was to evaluate the effect of walking speed and skill levels on the elbow flexion and the EMG activations of eight upper limb muscles across compared W and NW paired trials. A major limitation of the work is the limited number of subjects and the variability of poling techniques during NW for beginners as shown in Figure 1.b for subject B3. On the contrary, small values of the intra-subject variability were represented by narrow SD bands for E2 and B4 (Fig. 1.a), encouraging future tests.

There was little effect of the walking speed on the elbow R.O.M. for the expert E2, whereas a speed increase reduced the elbow R.O.M. for beginner B4 (Figure 2). The opposite speed effect was evident in beginner B4 for the peakEMG signals that consistently increased with increasing speed: the expert E2 data (Table 2) showed lower peakEMG increments.

Most activated muscles in the expert E2 during NW were respectively LD, TBCL, ERSP, DP and OEA, as shown by peakEMG values expressed as percent of MVC in Table 2. On the other hand, the need of a paired differential analysis with control walking trials at each speed was confirmed by the evidence of non-zero EMG curves during walking (eg. Figure 3).



(a) **(b)**

Figure 4: Effect of Nordic Walking Speed on the TBCL EMG signal on Expert E2 (Plot a) and Beginners B4 (Plot b).

Table 2. Table of results for comparison between Expert and Beginner analysed subjects.

		Expert (E2)			Beginner (B4)		
Muscle	**Values**	**MAX V**	**80%**	**60%**	**MAX V**	**80%**	**60%**
Elbow Angle	**Max Flexion**	+ 57°	+ 57°	+ 57°	+ 32°	+ 42°	+ 47°
	Min Flexion	- 01°	- 07°	- 05°	+ 12°	+ 05°	+ 07°
TBCL	**NWpeakEMG [% of MVC]**	68%	71%	57%	43%	31%	22%
	ΔEMG=(NW-W) [% of MVC]	+56%	+63%	+53%	+13%	+23%	+20%
DP	**NWpeakEMG [% of MVC]**	46%	37%	40%	76%	33%	20%
	ΔEMG=(NW-W) [% of MVC]	+33%	+25%	+30%	+40%	+18%	+12%
LD	**NWpeakEMG [% of MVC]**	90%	91%	80%	37%	22%	13%
	ΔEMG=(NW-W) [% of MVC]	+71%	+82%	+72%	+01%	+04%	- 10%
PECMSH	**NWpeakEMG [% of MVC]**	19%	20%	17%	26%	14%	06%
	ΔEMG=(NW-W) [% of MVC]	+13%	+15%	+14%	- 03%	+04%	+01%
TRM	**NWpeakEMG [% of MVC]**	14%	10%	08%	27%	13%	08%
	ΔEMG=(NW-W) [% of MVC]	+01%	- 01%	- 01%	- 04%	-06%	- 02%
TRS	**NWpeakEMG [% of MVC]**	07%	06%	06%	45%	40%	22%
	ΔEMG=(NW-W) [% of MVC]	+04%	+04%	+04%	- 10%	+16%	+05%
OEA	**NWpeakEMG [% of MVC]**	43%	36%	30%	15%	10%	04%
	ΔEMG=(NW-W) [% of MVC]	+06%	+05%	+04%	- 06%	+03%	00%
ERSL	**NWpeakEMG [% of MVC]**	51%	45%	38%	60%	51%	31%
	ΔEMG=(NW-W) [% of MVC]	+00%	+01%	+07%	-11%	+17%	- 02%

Furthermore, very low values of ΔEMG_{MUSCLE} for muscles like ERSL and OEA suggested that NW has an incremental effect for well trained subjects only on specific muscles like LD, TBCL and DP. The beginner experienced much lower increments on the same muscles.
The proposed method seems appropriate for quantifying the effect of Skill and Speed on the elbow ROM and the EMG activity of selected upper limb muscles.

CONCLUSIONS: As supposed, the need for proper training of beginners in correct technical execution and the maximization of sport advantages was evident from these pilot tests. A skilled subject maintained its elbow R.O.M. at increasing walking speed and maximized the increment of EMG activation on specific muscles like LD, TBCL & DP. An unskilled subject reduced significantly its elbow R.O.M. at increasing walking speed and experienced much lower increments of EMG activation only on TBCL and DP muscles. Further tests may support statistically the results of the present work.

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