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Timing In Sports Performance: Psychophysiological Analysis Of Technique In Male And Female Athletes

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ABSTRACT

The purpose of the present study was to examine if timing may be determined through differences in muscle tension. One hundred and six athletes (77 male and 29 female), from several technically-demanding disciplines within sports (20 archers, 50 golfers, 17 ski marksmen, 10 mini-golfers, 6 rifle marksmen, 2 discus casters and 1 boxer) participated in the study. The participants were divided into three groups: International level, National level and Club level. Each participant was then instructed to carry out his/her action technique, precisely as usual, in the respective sport. Electromyography (EMG) registered impulses from the chosen muscles (extensor digitorum and flexor digitorum). Results indicated that athletes at international level mobilize both muscles in complete or near-complete synchrony compared with athletes at national or club levels. Furthermore, international level athletes evidenced lowest peak amplitudes for bending and stretching during each respective activity. The findings are important to sports psychology and have many implications such as contributor to performance prediction and in terms of therapeutic implications.

Introduction

The concept of Flow, defined as ”an optimal psychological state in which complete absorption in the task at hand leads to a number of positive experiential qualities” (Jackson, 2000, p.135), has achieved a progressively greater attention within the sports psychology literature (e.g., Jackson, 1996; Jackson, Kimiecik, Ford & Marsh, 1998; Pates, Oliver & Maynard, 2001). Higher behavioral efficiency has been attributed to the influence of the flow state (Canter, Rivers and Storrs, 1985) but the physiological correlates to flow have been scarcely investigated and have been only generally or partially described, or in the case of somatic and neural responses, not described at all (Marr, 2001). Jackson (1995) noted that factors obstructing or disturbing flow of athletes are considered generally to be uncontrollable. One such important basal component is ”physical readiness” (Jackson, 1992) which is necessary for the coordination of all the units of movement involved. Physical readiness may be interpreted as a putative mind-body collaboration to accomplish the ’timing’ of muscle activity (e.g., Benvenuti, Stanhope, Thomas, Panzer, & Hallet, 1997; Hase & Stein, 1999; Strauss & Klich, 1999). Timing may be defined as ”temporal coordination of parallel activities or actions” (Nationalencyklopedins ordbok, 2000). More explicitly, timing involves the temporal coordination of agonistic and antagonistic muscle groups to facilitate even and effective movements by the limbs involved (Williams & Barnes, 1987), e.g. electromyographic (EMG) studies demonstrate the curbing effect of antagonistic muscles in inhibiting sharp/abrupt limb movement. These types of studies pertain also to the necessity of taking into account gender differences with regard to both intensity and acceleration of movement (Buchman, Leurgans, Gottlieb, Chen, Almeida, & Corcos, 2000).

Technical skill affects both timing and muscle tension. Aggelousis, Mavromatis, Gourgoulis, Pollatou, Malliou, and Kioumourtzoglou (2001) performed a study involving 41 subjects, aged 19-26 years, who were required to develop a new way (taking the elbow as starting point) of ’throwing a ball’. EMG-analysis of four muscles in the elbow region showed that conditions allowing more training gave better performance accompanied by reduced tension in the agonist muscle (biceps brachii) and in the most important antagonist muscle (aconeus). These results confirmed those of an earlier study (Engelhorn, 1988) on children aged 7-11 wherein better performance through exercise was associated with reduced EMG-activity in the muscles analyzed.

The influence of psychological variables upon timing and EMG analysis of muscle tension has been subject to investigation (Braathen & Svebak, 1990) indicating effects of frustration (Rychtecky, 1978), anxiety and worry (Adam & van Wieringen, 1988), deep relaxation with Flotation-REST (Norlander, Bergman & Archer, 1999), fantasizing (Harris & Robinson, 1986) and meditation (Harris & Robinson, 1986). Bird (1987) describes an experimental case-study in which an elite level 23-year-old rifle marksman demonstrated that the most successful performances were associated with ability to attain relatively low levels of cortical activation. Between ’taking-aim’ and ’firing’ EEG-amplitude remained stable until an instant before firing, when it descended sharply, rising again to normal level after firing. Lower levels of EEG during a series were associated with higher scores. Further, Janson (1995) reported a series of case-studies indicating that the most successful athletes within different disciplines (bowling, boxing, archery, discus, shot put, hammer, javelin, cycling, golf, marksmanship and weight-lifting) often produced lower EMG levels, pre-, during- and post-action, than less successful athletes, in each respective sport, for the critical muscles: this finding was confirmed even in the case of boxing. Janson (1995) noted too that elite athletes showed a markedly higher degree of synchronization between agonist and antagonist muscles as compared to those less skilful. Norlander et al (1999) reported that international-level archers had lower peak amplitudes during performance as compared to other level archers after both relaxation and non-relaxation conditions.

Against this background, five hypotheses have been derived in the present study: (a) international level athletes show superior ’timing’ (i.e., a closer synchrony of bending-stretching) than those at club level, (b) international level athletes show lower peak amplitude values for bending and stretching, respectively, compared to those at club level, (c) international level athletes show lower mean muscle tension over the complete action sequence than those at club level, (d) international level athletes show lower mean muscle tension immediately prior to ’firing’, ’throwing’, ’hitting’ or ’lifting’ than those at club level, and (e) international level athletes show lower mean muscle tension immediately after the ’firing’, ’throwing’, ’hitting’ or ’lifting’ than those at club level.

Method

Participants

106 athletes, including 50 golfers, 20 archers, 17 ski marksmen, 10 mini-golfers, 6 rifle marksmen, 2 discus casters and 1 boxer, of whom 77 were male and 29 female. The mean age of the participants was 27.68 years (*SD* = 9.18, *age range* = 12 to 60). Of the participants, 41 % indicated a small town-village home, 27 % a medium-sized town and 38 % a large-town or city abode. Participants were divided in three performance level groups: International level, National level and Club level (see ”Design”). One-way ANOVA did not indicate any significant differences due to age regarding performance ($p = 0.374$). There were no significant differences either (Kruskal-Wallis) between performance groups with regard to village, town or city residence ($p = 0.563$). There was a Gender imbalance by which more male participants were distributed to the groups, but female participants were quite equally distributed within groups

(International level: 10 women, National level: 10 women, Club level: 9 women)

Design

Each participant from the different sports disciples was submitted to an estimation process, in order to facilitate comparisons, based on current performance level, according to a 1-to-10 scale with each step defined as follows: 1 = new to the sport, 2 = has had a number of training opportunities, 3 = trains regularly, 4 = is ready for competition, 5 = average performance level, 6 = high performance level and competes in Club competition, 7 = competes in National competitions, 8 = National competitions with good results and some experience of international competitions, 9 = member of National team, 10 = World class level of performance. The estimates in each case were carried out by 2-3 national coaches of repute with assess to each participant in each respective sport. It is postulated that the coaches' estimates within each sport displayed almost total agreement so that no problems whatsoever were encountered in the assignment of participants' performance level. The variation was from four points to ten points. Thereafter the participants were divided into three groups (*cut-of-points* = 29.2%, 74.5%), i. e., Club level (M = 5.65, SD = 0.61, *scale-steps* = 4 – 6, n = 31), National level (M = 7.00, SD = 0.00, *scale-steps* = 7, n = 48), and International level (M = 8.59, SD = 0.75, *scale-steps* = 8 – 10, n = 27). One-way ANOVA followed by post hoc Tukey HSD-testing indicated significant differences in the performance levels between all groups, thereby constituting the independent variable Performance group. A second independent variable was defined by Gender (Male, Female). The dependent variables were EMG-measurements taken from the Flexor Digitorum and Extensor Digitorum muscles.

Instrument

EMG (Electromyogram Analysis). Measurements were carried out through application of an EMG-apparatus, Myo 2.4 (EMG-Konsult, Solna, Sweden). Myo 2.4 is a compact microprocessor-directed unit with two channels, sampling frequency capacity of 500 Hz, that transmits measured data, in real time, via A/D to a PC. 500 Hz is a sufficient sampling because the frequencies cover the signal area that the muscle fibers concerned react to most adequately (Janson, 1995). If one wishes to use quicker frequencies, an Oscilloscope must be used. Against the background of hypothesis formulation, this was not necessary. Two electrodes were placed at each side of the motorpoint at both flexor digitorum and extensor digitorum. The distance between the centrums of electrodes was 45 mm. The motorpoint was detected through a procedure using an electrical stimulant according to established techniques used in hospitals (Norlander, Bergman & Archer, 1999). A third electrode, the reference electrode was placed over os ulna for each muscle. The construction maintains high impedance, more than 10 000 Ohm. Signals may be distorted by artifacts, so these are "washed" through a low passage filter (f_g = 7Hz). Together the high impedance and the filter eliminate the risk for artifacts. This was tested for by letting the entering contacts be 'coupled' and by quite simply shaking the cables and checking that no artifacts occurred. The only thing that can influence the continuous curve, which ought to be zero always during "silent muscles" (i.e. during inactivity), is the voltage occurring during muscle activity, that is when the subject applies that muscle under observation. In order to control further the properties of the system, all the three points of measurement were connected the two measuring electrodes, differential measurement, and the reference electrode.

The rectified information (i.e., that the system presents intergrated EMG-curves) is accumulated in a Windows-based program. The signals are transmitted via infrared light beams from Myo to the PC. Consideration for subjects' safety is guaranteed through the precaution of maintaining a galvanized protection of the apparatus from network tension. Transmission is maintained with a standard 9V battery. The presentation can be performed through integration, e.g. mean amplitude, peak amplitude or duration. The sampling frequency allows opportunities for registration of action potentials in motor units (MUAPs), to the order of 10 mSecs, on application of surface electrode. Transmission (wireless) communication, telemetry, is applied from the source of action (active athlete) till Myo 2,4.

Regarding the temporal aspect, a so-called 'sweep time' may be regulated for up to 3 min. However, one may preserve that computer program and print out longer time periods. The spatial aspect is the area of measurement that may be registered, i.e. the amplitude that stretches from 0 to 100 or 150%. In the program there is the possibility of adjusting the amplitude on the screen up to 150% Maximal Volontary Contraction (MVC), which allows the subject to exceed his/her MVC value. At high exertion, with a high level of arousal, a user may recruit more than MVC. Regarding activity in the registered muscles, the curve, which is linear, completely based upon MVC, a well-known and documented research method. In the program developed for this type of registration one may conclude that the linear registration in percent coincides with the work carried out by the muscle. Thus, all registration is referred to as quantification. In this study, the percent registration based on MVC refers to our quantification. The accumulated registrations may be exported to the Excel computer program. The image projected on the computer screen may be "enlarged" several times to a level of accuracy of one hundredth part of a second and one hundredth percent of muscle activity.

In order to measure the impulses in the contractions of the chosen muscle groups (i.e., extensor digitorum and flexor digitorum), two surface electrodes were attached to the skin surface directly above each respective muscle at the underarm site (medial, central), a third surface electrode, the reference electrode, was attached to the skin above the ulna bone. Flexor digitorum was chosen since this muscle is responsible for bending movements primarily regarding the fingers but also those of the wrist. Consequently, the muscle critically affects the fine motor control that an athlete requires in a variety of different sports. Extensor digitorum was chosen with regard to its antagonistic action to flexor digitorum. It is expected that both flexor digitorum and its most important antagonist (i.e., extensor digitorum) ought to maintain an as high as possible degree of relaxation in order to ensure the most skillful sports performance. During EMG-measurements MVC is applied, see Procedure.

Following dependent variables were identified (cf., Norlander, Bergman & Archer, 1999) from the EMG-measurements: (a) Mean tension (EMG-MT), the average muscle activity during the complete activity, over 3 sec, (b) Pre-release tension (EMG-Pre), the average muscle activity during the 0.1 sec immediately prior to the 'trigger-squeeze', 'drive', 'hit' or 'throw', (c) Post-release tension (EMG-Post), the average muscle activity during 1 sec immediately after the completed action (the 'trigger-squeeze', 'drive', 'hit' or 'throw'), (d) Peak amplitude value (EMG-PA), the peak amplitude for each muscle that occurs exactly at incidence of the 'trigger-squeeze', 'drive', 'hit' or 'throw', (e) Amplitude difference quotient (EMG-AD), an estimate of the difference between EMG-PA for extensor digitorum and flexor digitorum, respectively. The difference is measured in secs and multiplied by 100, providing a quotient that avoids result description of exponential levels.

In addition, the ordering of the peak amplitudes (EMG-PA), i.e. the extent to which (1) mobilization of extensor precedes the mobilization of flexor, (2) there exists synchronous mobilization of extensor and flexor, (3) mobilization of flexor precedes mobilization of extensor. A synchronous mobilization of extensor and flexor requires 0 or close to 0 (within 10 msec).

Procedure

In collaboration with sports organizations concerned, athletes within certain technical-demanding disciplines (i.e., archery, discus, golf, mini-golf, ski and rifle marksmanship and boxing) were invited to participate in an investigation that took place at 10 different venues associated with different sports centers around Sweden, at different occasions. 106 athletes responded to the invitation. When the participants had arrived at each respective center they were informed of the purpose of the study and the objective of collecting data on the changes of muscle dynamics inherent to the EMG technique involved. The surface electrodes were placed on the lower arm over the extensor digitorum and flexor digitorum, the right lower arm and the left lower arm for right-handed and left-handed persons, respectively. In total, six electrodes were placed (2 + 2 measuring electrodes and 1 + 1 reference electrodes), which meant 3 electrodes over each respective muscle. The precise emplacement of the electrodes is an absolute prerequisite for ensuring maximal reliability and validity. Each participant was required actively to tense the muscles under study in order to facilitate and make sure of the exactitude of electrode emplacement. In order to maximize the contact surface and adhesiveness of the electrodes, the skin surface was shaved, washed with sterilizing spirits (Alsolspirit) and finally gently filed. An careful application of the electrode is an ultimate prerequisite, the point of application near motor point is controlled using a special apparatus giving low voltage and indicating contraction, for example in the finger just above the motor point. When this has been confirmed, then the process involved in the technique to fasten the electrodes is one requiring extreme care. The electrodes are a high standard, disposable type used with gel. They are placed side-by-side such that the center of each respective electrode is placed on each side over the Motor Point lengthwise. The distance between the center of the electrodes was 45 mm. When the electrodes had been placed the participant was instructed to carry out a Maximal Voluntary Contraction (MVC) of each, the extensor digitorum and flexor digitorum. MVC proceeds thus: the participant must tense each respective muscle several times to his/her maximum capacity several times against a solid object. The apparatus registers the highest values, which are then calibrated through the computer of the Experimenter. Through a transmitter in the EMG-apparatus calibration occurs independent of channel which takes into account any variations of skin resistance within any given individual and between individuals.

Each participant was then instructed to carry out his/her action technique, precisely as usual, in the respective sport. Thus, for example competitive archers were required to perform within the normal competition-length indoor field that is range of 18 meters and a 40-cm target, whereas golfers were presented the task of reaching a target lying, 60 meters distant, on the floor of an indoor course. After a warm-up period, the participants performed at least 6 actions (i.e. shooting six shots or driving six golf balls or releasing six arrows, etc.). Through a randomly arranged process, three measurements were taken as raw data for statistical analysis. Following all the tests, participants were presented a summary of their performances on the computer screens in order to see for themselves how they had, shot, driven, released arrows, thrown, etc.

Results

Reduction of data

In order to facilitate statistical analysis, the possibility of achieving a reduction of the data from the three measures taken with regard to the peak amplitudes (EMG-PA), amplitude difference quotient (EMG-AD), pre-release tension (EMG-Pre), post-release tension (EMG-Post) and mean tension (EMG-MT) for flexor digitorum and extensor digitorum, respectively, was analyzed. Thus, regression analysis (enter-method) was applied to calculate Multiple R (R). Significant correlations between the three measurements, taken from each participant, were indicated for EMG-PA regarding flexor digitorum ($R = 0.93$, $p < 0.001$) and extensor digitorum ($R = 0.90$, $p < 0.001$), for EMG-AD ($R = 0.74$, $p < 0.001$), for EMG-Pre regarding flexor digitorum ($R = 0.83$, $p < 0.001$) and extensor digitorum ($R = 0.90$, $p < 0.001$), for EMG-Post regarding flexor digitorum ($R = 0.88$, $p < 0.001$) and extensor digitorum ($R = 0.87$, $p < 0.001$), for EMG-MT regarding flexor digitorum ($R = 0.89$, $p < 0.001$) and extensor digitorum ($R = 0.90$, $p < 0.001$).

Since the regression analyses indicated acceptable ($R > 0.70$) or high ($R > 0.90$) values it was decided that the mean values of the three measures would be applied for the variables examined.

Dependent variables

A Pillais’ MANOVA (3 x 2 factorial design) was applied with Performance group and Gender as independent variables and with the averaged results for peak amplitude value (EMG-PA) for flexor digitorum and extensor digitorum, respectively, amplitude difference quotient

(EMG-AD), pre-release tension (EMG-Pre) for flexor digitorum and extensor digitorum, respectively, post-release tension (EMG-Post) for flexor digitorum and extensor digitorum, respectively, as well as mean tension (EMG-MT) for flexor digitorum and extensor digitorum, respectively, as dependent variables. The analysis indicated significant results both for Performance group (p = 0.028, Eta^2 = 0.15, *power* = 0.95) and for Gender (p = 0.016, Eta^2 = 0.19, *power* = 0.90), but not for Interaction effect between Performance group and Gender (p = 0.568). The results from the univariate F-test with regard to Performance group and Gender are presented below. Mean values and standard deviations are presented on Table 1.

Table 1. Peak amplitude values (PA), difference in amplitude quotient (AD), pre-release tension (Pre), post-release tension (Post) and mean tension (MT), for flexor digitorum (Flex) and extensor digitorum (Ext), respectively, as distributed over Performance level group (Club, National and International levels) and Gender (Male, Female). Values are expressed as means and (standard deviations)

	Club level		National level		International level	
	Male	Female	Male	Female	Male	Female
PA						
Flex	41.84 (35.57)	32.15 (32.28)	47.24 (31.37)	48.73 (40.12)	27.77 (29.58)	15.01 (17.89)
Ext	17.70 (13.27)	39.76 (32.42)	29.05 (23.22)	35.00 (29.43)	18.19 (19.66)	17.37 (13.05)
AD						
Quot	4.47 (5.89)	2.81 (3.94)	3.33 (4.23)	2.38 (1.20)	0.80 (1.14)	0.17 (0.28)
Pre						
Flex	9.99 (9.28)	15.76 (9.82)	8.45 (7.08)	13.82 (8.29)	6.41 (5.97)	8.01 (5.74)
Ext	6.68 (4.56)	13.09 (10.94)	8.83 (7.52)	11.81 (8.17)	5.49 (6.15)	9.35 (7.11)
Post						
Flex	8.66 (7.03)	7.53 (6.42)	7.42 (5.15)	7.51 (5.10)	5.77 (6.90)	3.44 (11.33)
Ext	6.44 (7.80)	9.42 (4.29)	6.68 (5.74)	9.73 (9.07)	8.26 (11.36)	4.01 (3.05)
MT						
Flex	10.40 (6.56)	15.89 (10.10)	8.05 (5.03)	13.60 (7.88)	6.49 (4.44)	7.22 (5.45)
Ext	7.09 (3.51)	12.20 (7.05)	8.18 (4.80)	12.08 (6.14)	7.33 (5.47)	9.36 (7.78)

Peak amplitude value (EMG-PA). Univariate F-test indicated a significant result for flexor digitorum with regard to Performance group [F (2, 99) = 5.09, p = 0.008, Eta^2 = 0.09, *power* = 0.81], whereby post hoc testing (Tukey-HSD) indicated that participants at the International level showed lower peak amplitude for flexor muscle (M = 23.04, SD = 26.24) compared to those at the National level (M = 47.55, SD = 32.91), whereas there was no significant difference compared to those at Club level (*M* = 39.03, *SD* = 34.40). Regarding extensor digitorum, there was a tendency (*p* = 0.055) by which the International level group indicated the lowest peak amplitude for extensor (*M* = 17.88, *SD* = 17.23) compared with the National level (*M* = 30.29, *SD* = 24.42) and Club level (*M* = 24.11, *SD* = 22.52).

Univariate F-test indicated no significant differences for flexor digitorum regarding Gender (*p* = 0.371), but there was a non-significant tendency towards a Gender difference regarding extensor digitorum (*p* = 0.07), whereby further analysis indicated that female participants (*M* = 30.40, *SD* = 27.02) tended to show higher peak amplitudes than male participants (*M* = 23.41, *SD* = 20.59).

Amplitude difference quotient (EMG-AD). Univariate F-test indicated a significant effect of Performance group [*F* (2, 99) = 4.47, *p* = 0.014, Eta^2 = 0.08, *power* = 0.85], whereby post hoc testing (Tukey-HSD) indicated that participants at the International level showed a smaller difference between the amplitude peaks of flexor and extensor (*M* = 0.57, *SD* = 0.96) compared with both the National level (*M* = 3.13, *SD* = 3.87) and Club level (*M* = 3.99, *SD* = 5.38) groups. There was no significant difference between the National and Club levels. There was no significant effect of Gender for EMG-AD.

Pre-release tension (EMG-Pre). Univariate F-test indicated a significant effect of Performance group for flexor digitorum [*F* (2, 99) = 3.68, *p* = 0.029, Eta^2 = 0.07, *power* = 0.66], whereby post hoc testing indicated that the International level (*M* = 7.01, *SD* = 5.83) showed lesser muscle tension prior to action than both the National (*M* = 9.57, *SD* = 7.58) and Club (*M* = 11.67, *SD* = 9.64) level groups. There were no significant differences between the National and Club level groups. There were no significant effect for extensor digitorum (*p* = 0.312).

Univariate F-test indicated a significant effect of Gender with regard to flexor digitorum [*F* (1, 99) = 6.29, *p* = 0.014, Eta^2 = 0.06, *power* = 0.70], whereby further analysis indicated that the female participants showed higher values (*M* = 12.42, *SD* = 8.45) compared to male participants (*M* = 8.44, *SD* = 7.60). Further, there was a significant difference for Gender with regard to extensor digitorum [*F* (1, 99) = 7.43, *p* = 0.008, Eta^2 = 0.07, *power* = 0.77], whereby further analysis indicated that the female participants (*M* = 11.36, *SD* = 8.62) showed higher values compared with male participants (*M* = 7.48, *SD* = 6.58).

Post-release tension (EMG-Post). Univariate F-test indicated a non-significant tendency for flexor digitorum with respect to Performance group (*p* = 0.063), whereby participants at the International level tended to exhibit lower muscle tension post action (*M* = 4.90, *SD* = 5.96) compared with those at National level (*M* = 7.44, *SD* = 5.09) and Club level (*M* = 8.33, *SD* = 6.78). No significant differences were obtained for extensor digitorum on the EMG-Post variable (*p* = 0.606). There were no significant effects of Gender for either flexor digitorum (*p* = 0.451) or extensor digitorum (*p* = 0.769).

Mean tension (EMG-MT). Univariate F-test indicated a significant effect of Performance group for flexor digitorum [*F* (2, 99) = 7.17, *p* = 0.001, Eta^2 = 0.13, *power* = 0.93], wherby post hoc testing (Tukey-HSD) indicated that the International level participants showed lower total muscle tension (*M* = 6.76, *SD* = 4.75) than those at National (*M* = 9.21, *SD* = 6.08) and Club levels (*M* = 11.99, *SD* = 7.98), but there was no difference between the two latter. There were no significant effects of EMG-MT for extensor digitorum (*p* = 0.453).

Univariate F-test indicated a significant effect of Gender with regard to flexor digitorum [*F* (1, 99) = 8.81, *p* = 0.004, Eta^2 = 0.08, power = 0.84], whereby further analysis indicated that the female participants showed higher values (*M* = 12.11, *SD* = 8.52) in comparison with the male participants (*M* = 8.38, *SD* = 5.51). Further, there was a significant effect of Gender for extensor digitorum as well [*F* (1, 99) = 9.53, *p* = 0.003, Eta^2 = 0.09, *power* = 0.86], whereby further analysis indicated that the female participants showed higher values (*M* = 11.18, *SD* = 6.90) in comparison with the male participants (*M* = 7.69, *SD* = 4.59).

Analysis of Sports discipline

One-way ANCOVA with the three most highly represented disciplines (i.e. golf, archery and ski marksmanship) as independent variable, Performance level as covariate and with the EMG-measures of muscle tension as dependent variables did not indicate any significant difference for EMG-MT regarding extensor digitorum ($p = 0.304$), but did so for the other EMG-measures of muscle tension (ps < 0.001), confirming the existing notion that different sports place different demands upon muscle tension. The analyses carried out within each discipline nevertheless demonstrate an overall pattern that was almost universal over the individual sports disciplines. Statistical analyses were performed on the measures from the 50 golfers, the 20 archers and the 17 ski marksmen. The results obtained for Performance group and Gender were remarkably similar to the analyses of the whole group of athletes. Regarding the 10 mini-golfers, the 6 rifle marksmen, the 2 discus throwers and the single boxer, the material was too small to allow statistical analysis. Nevertheless, a descriptive analysis was carried out that was found to fit well with the overall analysis and the analysis for golfers, archers and ski marksmen. Table 2 presents the percent distribution of ordering of EMG-PA for the overall group of athletes at the first of the three randomly-chosen measures, i.e. the extent to which (a) mobilization of extensor precedes mobilization of flexor, (b) mobilization of extensor and flexor occur synchronically, (c) mobilization of flexor precedes mobilization of extensor.

Table 2. Frequency and percentage measures at the first measuring occasion with regard to peak amplitudes for extensor digitorum and flexor digitorum (extensor-flexor, simultaneous, flexor-extensor, respectively) as distributed within each respective Performance group level (Club, National and International levels) for all 106 participants.

	Club level		National level		International level	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Exten-flex	2	6.46	3	6.25	0	0.00
Simultaneous	20	64.51	24	50.00	23	85.19
Flex-exten	9	29.03	21	43.75	4	14.81
Total	31	100	48	100	27	100

It was not possible to carry out a test of significance with chi-square (Contingency table) since 3 cells received the expected value of less than 5, so that instead a test of significance was performed whereby synchronous mobilization of extensor and flexor was compared with those cases wherein synchronous mobilization did not occur during the 1st randomly-chosen measure. This analysis provided a significant result [Chi^2 (2) = 9.23, *minimum expected count* = 9.93, $p =$ 0.010] which indicated that participants at International level presented significantly more synchronous mobilizations of extensor and flexor in comparison with both the other groups. Similar results were obtained even for the second and third measures (ps < 0.05). The same pattern occurs in the observation of athletes who succeeded in obtaining synchronous mobilizations of extensor and flexor for all three measures (International level = 59.3 %, National level = 31.1 %, Club level = 41.9 %). As indicated, a similar pattern is often obtained for the different sports disciples, as described in Table 3.

Table 3. Proportion (in percent) of athletes who displayed synchronous mobilization of extensor digitorum and flexor digitorum during the three measurement occasions within each respective Performance group level (Club, National and International levels) for golfers (*n* = 50), archers (*n* = 20), ski marksmanship (*n* = 17), mini-golfers (*n* = 10), rifle marksmanship (*n* = 6), discus casting (*n* = 2) and boxing (*n* = 1).

	Club level	National level	International level
Golfers	15.4	23.3	28.6
Archers	27.5	16.7	83.3
Ski marksmanship	77.8	100	100
Mini-golfers		33.3	57.1
Rifle marksmanship	100	33.3	100
Discus casting		100	100
Boxing			100

Discussion

The five hypotheses presented above may be discussed in turn on the basis of the present results obtained.

(a) Athletes at the International level demonstrate better timing (i.e. the synchronous mobilization of flexor digitorum and extensor digitorum) compared with athletes at Club level. This hypothesis was confirmed to the extent that the difference between the peak amplitudes for flexor and extensor was smaller in comparison with both the National and Club level groups. Peak amplitudes occur in association with ”action-release” of the drive, shot or throw. Furthermore, it was found that the International level group had significantly more synchronous mobilizations of flexor digitorum and extensor digitorum than the other groups. Surprisingly, there were no differences between the National and Club level groups regarding peak amplitude difference and the Club level group did show a higher percentage of simultaneous mobilizations of agonist and antagonist, compared to the National level group, after the three measures. One explanation may be that the Club level athletes had lower ’expectancy’ and thereby a lower level of ’performance-pressures’ allowing them to perform their actions in a relaxed, natural manner. Athletes at a certain level of experience and with certain self-imposed demands may be expected to exert more conscious control over events. Through intensive training, may these athletes performed at superior levels to those at Club level although the inherent tensions serve to interfere with optimal timing thereby presenting a hindrance to stepping up to International level. This timing mechanism does not appear to be Gender-related as there were no effects of Gender

nor any Performance x Gender interaction effects on timing.

(b) International level athletes show lower peak amplitude values for flexor and extensor, respectively, than Club level athletes. This hypothesis too was confirmed in the International group, i.e. they showed the lowest peak amplitude values for flexor and a strong similar tendency for extensor, confirming the results of (1987) and Janson (1995). Nevertheless, it was not expected that the National group showed the highest values for both flexor and extensor. This finding reinforces the conclusion drawn from the a-hypotheses namely that several athletes at the National level were afflicted by ”unnecessary” muscle tension. There were no Gender differences here either even though the women tended to show higher peak amplitude values than the men.

(c) International level athletes show lower average muscle tension during the complete action than Club level athletes. The pattern of the previous results, (1) and (2), was replicated, generally: the International group showed lower total muscle tension in flexor digitorum than both the National level and Club level groups. However, there was no effect of Performance level regarding extensor digitorum. It ought to be noted that there were no effects of sports discipline on extensor digitorum for the average muscle tension during the complete action despite the different levels of effort required in the disciplines. It is possible that the athletes involved were secure in the knowledge that the test measures were being taken without particular ’competitive’ performance requirements. Differences due to performance level during extensor engagement may be forthcoming under conditions of competition because the antagonist muscles (in most cases a stretch muscle) are engaged first, i.e. the stretch reflex is quicker than the bend reflex. It may be that certain defensive mechanisms initiate a reaction associated with ‘performance stress’ (Larsson, 1991, Pinell, 2000). There was a clear Gender effect upon muscle tension during the complete action, whereby female athletes showed higher values than male athletes for both flexor and extensor. One possibility, pertaining to flexor digitorum, is that the women required mobilization of greater muscle effort in order to complete a given action; on the other hand, the higher tension level in extensor may be caused by an, as yet, unexplained level of ‘performance stress’ during measurements.

(d) International level athletes show lower average muscle tension immediately before the shot, hit or throw than Club level athletes. The observed pattern, during the complete action, was evidenced also immediately before (0.1 sec) the action itself, i.e. International level participants showed lower levels of tension in flexor digitorum compared to both National and Club level participants, whereas there were no differences regarding extensor digitorum. Similar Gender effects were observed whereby female participants displayed higher values than males for both flexor and extensor.

(e) International level athletes show lower average muscle tension immediately after the shot, hit or throw than Club level athletes. The observed pattern, was evidenced also immediately after (1 sec) the action itself, i.e. International level participants showed a clear tendency to lower tension in flexor digitorum compared to both National and Club level participants, whereas there were no group differences with regard to extensor digitorum. There were no differences in regard to Gender either for flexor digitorum or extensor digitorum.

This summary of the results indicates that the hypotheses were confirmed in the case of the International level group, not only regarding the overall analyses but also in each discipline itself. For example, after three measurements the International group showed the greatest number of synchronous mobilizations of agonist and antagonist within golf, archery and mini-golf as well as perfect timing at all three measurements for ski marksmanship, rifle marksmanship, discus and boxing. A closer analysis at discipline level seems necessary in order to describe the mechanisms involved in timing with more certainty. It would appear that the relationships between National and Club level performances need to be better understood. For the most part there were no differences in muscle tension between these levels and, indeed, after three measurements the Club level participants achieved more synchronous mobilizations. Nevertheless, the National level group performed better than the Club level. There was no age difference between these two groups and there was no interaction between performance level and Gender. It is possible that although the National level achieved better results, due mainly to more training dedication, certain irregularities in muscle tension, perhaps due to stress-anxiety, preclude the major step up to the International level.

The present study had some limitations. The participants' actual performance was not recorded and used for comparisons. Further, data from other muscles than the two used in the study would have been useful. This should be addressed in future studies. Future studies should also seek to carry out measurements under conditions of competition. An earlier study (Norlander, Bergman & Archer, 1999) showed that deep relaxation through the application of a Flotation-REST technique, immediately prior to competitive archery, reduced significantly muscle tension in extensor digitorum thereby reducing degree of effort whereas the best archers demonstrated more constancy shooting than the least skilful archers. This difference was not observed in the condition that did not receive Flotation-REST. It possible that under competitive conditions differences between performance levels, regarding extensor, are more clearly evident. Further, possible Gender differences in EMG-measured muscle tension and timing in sports performance ought to be carefully analyzed by taking into account the biological and behavioral prerequisites in the underlying mechanisms. It is important that future studies investigate possible connections between good timing and different flow components and thereby adding to our knowledge of psychological factors and muscle tension. Finally, the issue of whether muscle tension and sports performance are related is important to sports psychology research and application and is certainly a valuable area for future research given its potential for applied implications, e. g., as contributor to performance prediction and in terms of therapeutic implications.

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