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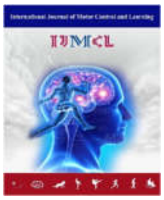

Expertise Influence on Anticipatory Postural Adjustment under Different Temporal Pressure

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ABSTRACT

Background: Skilled athletes' optimal performance might be due to their postural ability to counteract perturbation. However, how expertise influences coordination of anticipatory postural adjustment (APA) and main movement under temporal pressure needs more investigation. This study aimed to investigate how available time (temporal pressure) for central nervous system to prepare postural and motor commands, differentiates skilled and novice postural capacity during performing Table Tennis Forehand stroke.

Methods: 10 skilled (20.3±1.15 years old) and 10 novice (19.9±0.99 years old) Table Tennis players while maintaining Forehand stroke position on two force plates, stand in front of a screen that presenting Coincident Anticipation Timing stimulus. Participants completed a block of 20 trials consisted of random-order presentation of fast and slow stimuli and surface muscle activity of postural muscles were recorded using Electromyography device, simultaneously.

Results: The results of two-way MANOVA showed that, more/less temporal pressure for central nervous system led to later/earlier onset time of APA with lower/higher magnitude, respectively. Skilled players' postural strategy was higher magnitude of APA in dorsal muscles (Erector Spainae, Biceps Femoris and Gasterocnemous), more backward peak excursion and lower velocity of centre of pressure.

Conclusion: Although such findings may be beneficial factors for coaches in programming athletes' training, however, the similarity in anticipatory postural adjustments' onset time of novice and skilled players, do not let certain conclusion about the effects of expertise on feed-forward control of posture.

1. Introduction

Fast voluntary goal-directed movements like those perform in sports field are susceptible to loss of equilibrium, unless feed-forward mechanism called Anticipatory Postural Adjustments (APAs) counteracts such perturbation caused by main movements (Massion, 1992). These postural activities which preceded motor commands are generated by Central Nervous System (CNS) to control the position of centre of pressure via reciprocal activation or co-contraction of trunk and leg muscles (Zhao, Watanabe, Asaka, & Wang, 2020). Two perspectives have been proposed on the relationship between voluntary actions and related APA. Based on the dual- parallel control model, APA is generated through two separate control structures. This system needs to receive information from the control structure used in operations to limit the timing and amount of APA according to the main operations. Thus, the APA controller is different from the controller for voluntary movements. In contrast, the single-process control model states that APA is a key part of actions and is controlled in full conjunction with voluntary actions (Slijper, Latash, & Mordkoff, 2002).

Differences in CNS mechanisms of APAs control and ability of subjects to perform movements may lead to different APAs' responses (Aruin & Latash, 1995). Researchers stated that learning a specific task accompanied by repetitive training and acquired experience lead to some permanent changes in performance parameters and electromyography (EMG) activities of movement (Schmidt, 1988). Therefore individual differences in APAs control might also be induced by repeated practice and experience (Saito, Yamanaka, Kasahara, & Fukushima, 2014). Although researches showed that some improvement in postural stability occurred as the result of learning the arm movement tasks (Aruin, Kanekar, Lee, & Ganesan, 2015; Galgon, Shewokis, & Tucker, 2010), repetitive training (Saito et al., 2014) or some sport training (Shin, 2019), it seems that these improvements were due to rapid short term adaptation to that presented task. Since researches about the effect of expertise on APA's onset time and magnitude during performance of specific skill (such as table tennis) are rare, so it is still unclear whether levels of expertise in some skills induced by long term learning and experience of specific task may differentiate feed forward postural control mechanism of subjects, especially during performing tasks that are constrained by temporal pressure.

Previous researches demonstrated that earlier APAs' onset and greater magnitude of APA is an indication of greater postural preparation in advance of the expected perturbation of ongoing voluntary action (Aruin et al., 2015) and it is documented that highly trained athletes exhibit a better postural performance (Liang, Hiley, &

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Kanosue, 2019; Powell & Williams III, 2015). Therefore, athletes of different sport disciplines developed an optimal APAs behaviour for their best athletic performance according to their postural demands (Popa, Bonifazi, Della Volpe, Rossi, & Mazzocchio, 2008). Also, modulation of timing and magnitude of APAs according to differences in postural demands is based on experience of similar movements (Paillard, 2019). Therefore, in this study it is hypothesized that expertise has some effects on modulation of APAs' onset time and magnitude under temporal pressure in that specific sport field. The Table Tennis sport is characterized by continuous fast arm movement which needs more postural demands and also, high temporal pressure induced by too much stimulus is observable. However, previous studies rarely investigate such APA's and main movement coordination under temporal pressure among table tennis athletes, specially, in differentiating skilled and novice players.

2. Materials and Methods

2.1. Subjects

Twenty male healthy right-handed participants based on Waterloo Handedness Questionnaire (Steenhuis & Bryden, 1989) - 10 skilled (20.3±1.15 years old) and 10 novice (19.9±0.99 years old) Table Tennis players - with normal vision, without any known neurological or skeletomuscular disorders and without any history of injuries participated in this study according to convenience sampling. According to sheppard and li (2007) definition, skilled Table Tennis players had at least 2 years records of playing, attending any competitions and playing Table Tennis for at least 2 hours per week (Sheppard & Li, 2007). Novice player selected from physical education students with no previous records of playing Table Tennis and who have recently passed Table Tennis course and became familiar with forehand stroke and its positioning. All the participants provided consent form. The experimental procedure was scientifically approved by research committee of Faculty of Physical Education and Sport Sciences, University of Tehran, and ethically approved by ethic committee of Sport Science Research Institute.

2.2. Apparatus and task

A combined wireless EMG system and accelerometer (2000 Hz sampling rate, 16-bit resolution, Myon, Aktos model, swiss) with disposable self-adhesive electrodes' chest lead (Skintact, Austria) was used to record the surface muscle activity of Tibialis Anterior (TA), Gastrocnemius (GA), Rectus Femoris (RF), Biceps Femoris (BF), Rectus Abdominis (RA) and Lumbar Erector Spinae (ES). These are the major postural muscles which are mostly used in studies of APAs (Chen, Lee, & Aruin, 2015; Shiratori & Latash, 2000; Slijper & Latash, 2004; Slijper et al., 2002). One channel of this Myon EMG system adjusted for recording acceleration of forehand stroke in three dimensions of x, y and z axes, which was placed on posterior side of wrist (parallel to Radius bone). Other pairs of electrodes were placed on innervations zone and aligned with the muscle fibre direction, on the shaved skin areas which were cleaned with alcohol prior to electrodes placement. The circular electrodes have 10 mm diameter and the centre of electrodes were 2 cm apart (Day, 2002), these electrodes were placed over the right side of the participants' body. electrodes were placed 2 cm lateral to first lumbar vertebrae for ES muscle (Hardie, Haskew, Harris, & Hughes, 2015), 50 % of distance between Anterior Superior Iliac Spinae and upper border of patella for RF muscle, and 50 % of distance between Ischial tuberosity and lateral epicondyle of tibia for BF muscle (Rashid, Ahmad, Haron, & Adnan, 2012). For GA muscle, the most prominent bulge of the muscle and for TA muscle, 1/3 on the line between the tip of the fibula and the tip of the medial malleolus (Merletti, 2000) was selected. For the RA muscle, the electrode was placed perpendicular to the horizon, 3cm lateral and 3cm superior to the umbilicus (Ekstrom, Donatelli, & Carp, 2007)

Two force platforms (AMTI, AccuGait-O, USA) were used to record the sheer force in Anterior Posterior (AP) direction (Fy), Medio-Lateral (ML) direction (Fx), the vertical component of reaction force (Fz) and the moment of force around the frontal axis (Mx) for each leg. EMG and force plate were synchronized together and data were sampled at 1000 HZ with 16-bit resolution. Data were collected by lab computer using Cortex software (Cortex7.0, Motion Analysis, USA).

The Coincidence Anticipation Timing (CAT) system (Padidar Omid Farda Company, Tehran, Iran) which has two software and hardware parts were used for running CAT tasks. The reliability and validity of this device were 0.83 and 0.87 respectively (Ramezanzadeh, 2011). The software part is designed for displaying light stimulus on the screen and is capable of setting stimulus velocity, stimulus colour, back ground colour and even adjusting angular path way with any considered information. The hardware part is consisted of two apparatus installed on stands in front of each other for sending out and receiving laser beam respectively. So, it makes a line of laser beam in front of participants which must be cut off with racquet in order to respond according to presented stimulus on screen. In order to ascertain the racquet to laser contact, a handmade bar with a real ball on top of the bar was placed in front of participants and exactly below the line of laser beam. The participants had to complete the Fore Hand stroke by hitting the ball in accordance with the stimulus. The stimulus was an orange-coloured circle representing a Table Tennis ball. This stimulus moves along a pre-designed curved path in a blue-coloured background (Figure 1).

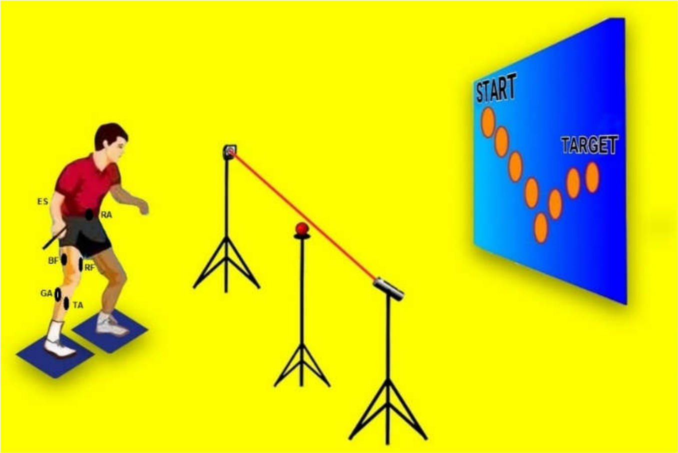

Figure 1. Experimental setup.

2.3. Procedures

General rules of the experiment and some descriptions for how to complete the task were told to each participant. After EMG electrodes placement, each participant stands bare feet on dual force platforms, with one foot on each force plate and feet shoulder width apart in front of the screen that presenting CAT stimulus. Skilled and novice participants take a Table Tennis racquet with Shake Hand grip manner. They had to keep the defined forehand stroke position at their own comfort and maintain that style until the end of experiment. No further instruction was given to them during experiment in order to remove any bias in their performance. The stimulus presented in random order in high (5 m/s) and low (1 m/s) velocity (Akpinar, Devrilmez, & Kirazci, 2012); so that according to the path length, participants had 0.7 second- and 3-seconds available time to prepare their motor action. After 10 trials of practice, participants completed a block of 30 trials consisted of random-order presentation of fast and slow stimuli with a 10 second delay between each trial for participants to maintain initial position. Participants must respond to each stimulus in a way that racquet passes across and cut the laser beam. From 30 recorded trials, the first five trials (due to warm up decrement effect) and last five trials (due to effect of tiredness) were removed. Therefore, 20 middle trials were selected for further processing.

2.4. Data Analysis

EMG and accelerometer signals were filtered with 50-Hz, and COP data was filter with 20- Hz, low-pass, second order Butterworth filter and rectified using customized Matlab 8.1 software (Matlab 8.1.0.604, MathWorks Ink, USA). The entire criterion for data processing was selected based on the method described in krishnamoorthy and latash (2005) as follow: The accelerometer data, after correction for offset, were used to find the movement initiation and it was defined as the point in time at which the accelerometer signal exceeded 1% of maximum acceleration. After visual inspection, this point was confirmed and referred to as time 0 (t0). Then data from 500 ms before t0 were selected for analysis. All time intervals were corrected for 50 ms electromechanical delay which is also cited by other studies (Klous, Mikulic, & Latash, 2011; Krishnan, Latash, & Aruin, 2012). The selected data divided in to three-time interval: the baseline interval (-500 ms to -300 ms), the transition interval (-300 ms to -200 ms), and the APA interval (-200 ms to 0 ms) (Klous et al., 2011). The baseline interval was compared between skilled and novice players to see whether there are different baseline muscle activities between two groups.

To find the onset time of APAs from EMG data, the instance in time when average muscle activation level in APAs time interval (i.e., -200 ms to 0 ms) over trials exceeded more than ±2.5 SD of the average value within the baseline time interval (i.e., -500 ms to -200 ms) (Klous, Mikulic, & Latash, 2012). These time intervals were selected since most researches showing that APAs typically occur about 0 to 200 ms before main movement initiation (Klous et al., 2011; Krishnan et al., 2012). Finally, these APAs onset times were confirmed by visual inspection.

To report the magnitude of APAs, that is the quantity of APAs activity, we consider the criterion used in (Slijper & Latash, 2004). First, EMG integral (IEMG) were calculated using trapezoidal rule of numerical integration from the calculated APAs onset time (as mentioned above) to t0 for each subject in each trial by equation (1):

Equation (1) $$\text{IEMG} = (t_{i+1} - t_i) \times ((\text{EMG}_i + \text{EMG}_{i+1})/2)$$

In equation (1), EMG is the samples of filtered data, ti is the time frame of EMGi and IEMG is the applied trapezoidal rule to each subinterval. Since EMG data were sampled at 1000 Hz, each time frame is 1 ms and the result of ti+1 – ti is always equal to 1 millisecond. Then, the APAs magnitude is calculated by summing the corrected IEMGs using equation (2):

Equation (2) $$\int\text{IEMG} = \sum_{n=\text{APAonset}}^{t0} \text{IEMG}$$

In equation (2), ∫IEMG is magnitude of APAs in one trial. Then these ∫IEMGs were corrected by subtracting the ∫IEMG activity of base line interval (i.e. -500ms to -200 ms) from ∫IEMG activity in APAs intervals in each trial as equation (3):

Equation (3) $$\int\text{IEMGC} = \int\text{IEMG} - \int\text{IEMG-500to-200}$$

In equation (3), ∫IEMGC is corrected ∫IEMG of each trial. ∫IEMG-500to-200 is the magnitude of EMG activity of base line interval. For each participant, the arithmetic average of corrected magnitudes of 10 trials in each situation was calculated. At the end, APAs' magnitude of 10 novice and 10 skilled players performing 10 fast and 10 slow stimulus trials were recorded for other statistical processes. However, for comparison across all participants, ∫IEMGC values were normalized through equation (4). the result of this equation ranged all the ∫IEMGC values in to -1 to +1 (Mohapatra, Krishnan, & Aruin, 2012).

Equation (4) $$\int\text{IEMGC-N} = \int\text{IEMGC} / \int\text{IEMGMAX}$$

In equation (4), ∫IEMGC-N is normalized and corrected APAs magnitude, ∫IEMGC is corrected APAs magnitude of each participant and ∫IEMGMAX is the maximum APAs magnitude in each group of fast/slow or skilled/novice variable.

To process COP data, first, time-varying COP of AP direction was calculated for each limb using the equation (5):

Equation (5) $$\text{COPAP} = (-\text{MML} + (\text{FAP.dZ}))/\text{FZ}$$

In equation (5), dz is the distance from the surface to the platform origin (0.043), F is force, M is the moment of force and FZ is the vertical component of reaction force. The resultant COP (COPNET) from the data of left (L) and right (R) force plate was calculated for AP direction using equation (6):

Equation (6)

$$\text{COPNET-AP} = [\text{COPL-AP} \times (\text{FZ-L} / \text{FZ-L+FZ-R})] + [\text{COPR-AP} \times (\text{FZ-R} / \text{FZ-L+FZ-R})]$$

In equation (6) the COPNET-AP is the resultant COP in anterior-posterior direction and FZ-L and FZ-R are the vertical reaction forces under the left and right feet respectively. Then displacement of COPAP was computed by subtracting the average COPAP coordinate during baseline from the COPAP coordinate during trials. To demonstrate the anticipatory COP behaviour, the magnitude of peak (the most opposite position of APACOP excursion), Velocity and RMS (variability) of COP excursion in AP direction were also calculated.

Independent-sample t test used for comparison of baseline muscle activities ((i.e., -500 ms to -200 ms before movement initiation) between skilled and novice players to confirm similar baseline muscle activities of both groups and multiple paired-sample t tests used for comparison of baseline (-500 ms to -200 ms) and APAs intervals (-200 ms to 0 ms) to confirm the existence of APAs (Klous et al., 2012). Also, data were analysed using two-way multivariate analysis of variance (MANOVA) with two independent variables of temporal pressure (fast and slow stimulus) and levels of expertise (skilled and novice), first for dependent variables of APA onset times of TA, GA, RF, BF, RA, ES muscles, second for APA magnitudes of TA, GA, RF, BF, RA, ES muscles and third for peak, velocity and RMS of COP excursion with Tukey test for paired comparisons, using SPSS (PAWS statistic.18, IBM company, USA). Statistical significance was set at $P \leq 0.05$.

3. Results

3.1. *EMG data*

Independent-sample t test shows that at baseline time interval, there is no statistically significant difference in IEMG activities of TA ($t_{(38)}$=0.969, P=0.338), GA ($t_{(38)}$=0.052, P=0.959), RF($t_{(38)}$=1.113, P=0.264), BF ($t_{(38)}$=0.040, P=0.968), RA ($t_{(38)}$=1.749, P=0.090) and ES ($t_{(38)}$=1.719, P=0.094) between skilled and novice players. Therefore, initial positioning of skilled and novice players made no substantial difference in IEMG activity of postural muscles. Also, multiple paired-sample t tests show that in TA ($t_{(39)}$=9.208, $P < 0.0005$), GA ($t_{(39)}$=6.480, $P < 0.0005$), RF($t_{(39)}$=7.031, $P < 0.0005$), BF ($t_{(39)}$=11.077, $P < 0.0005$), RA ($t_{(39)}$=11.975, $P < 0.0005$) and ES ($t_{(39)}$=9.849, $P < 0.0005$) the EMG activities of the APAs' interval are different (more than 2.5 SD) from that of base line interval. Descriptive data of postural muscles' IEMG activities for novice and skilled participants during baseline and APA intervals are presented in Table 1.

Table 1. Descriptive data of EMG activities.

Muscles	Expertise	N	Base line phase		APA phase	
			Mean	**SD**	**Mean**	**SD**
TA	Skilled	20	0.066	0.045	11.126	8.720
	Novice	20	0.056	0.021	10.892	6.359
GA	Skilled	20	0.040	0.012	7.163	6.404
	Novice	20	0.040	0.023	4.881	5.139
RF	Skilled	20	0.028	0.018	6.141	3.560
	Novice	20	0.033	0.008	6.216	7.084
BF	Skilled	20	0.021	0.007	7.852	3.943
	Novice	20	0.021	0.008	4.633	2.220
RA	Skilled	20	0.009	0.004	1.500	0.485
	Novice	20	0.012	0.006	1.537	1.038
ES	Skilled	20	0.053	0.023	7.823	3.488
	Novice	20	0.043	0.015	3.546	2.273

Note: Each subject performs 10 fast and 10 Slow trials. So, group number is according to their number of trials.

Table 2. Results of MANOVA test for onset time and magnitude of APAs of postural muscles.

Postural muscles		Levels of Expertise			Stimulus Velocity		
		F (1,36)	P	$p^{\eta2}$	F(1,36)	P	$p^{\eta2}$
TA	Onset time	1.518	0.226	0.040	224.587	< 0.0005*	0.862
	Magnitude	0.019	0.891	0.001	45.415	< 0.0005*	0.558
GA	Onset time	3.085	0.088	0.079	594.619	< 0.0005*	0.943
	Magnitude	7.277	0.011*	0.168	23.592	< 0.0005*	0.396
RF	Onset time	0.004	0.949	0.000	215.589	< 0.0005*	0.857
	Magnitude	0.002	0.966	0.000	8.409	0.006*	0.189
BF	Onset time	4.021	0.053	0.100	110.824	< 0.0005*	0.755
	Magnitude	11.343	0.002*	0.240	8.460	0.015*	0.152
RA	Onset time	0.053	0.819	0.000	101.680	< 0.0005*	0.739
	Magnitude	0.023	0.880	0.001	6.709	0.013*	0.159
ES	Onset time	3.847	0.058	0.097	652.590	< 0.0005*	0.948
	Magnitude	98.055	< 0.0005*	0.731	200.627	< 0.0005*	0.848

Note: TA= Tibialis Anterior, GA= Gasterocnemius, RF= Rectus Femoris, BF= Biceps Femoris, RA= Rectus Abdominis, ES=Erector Spinae. * Shows significant effects.

3.2. *Effect of stimulus velocity on APA*

The results of two-way MANOVA showed that, based on different stimulus velocity, there was a statistically significant difference in onset time, F (6, 31) =327.77, P < 0.0005; Wilk's λ = 0.016, partial η2 =0.984 and magnitude, F (6, 31) =53.31, P < 0.0005; Wilk's λ = 0.088, partial η2 =0.912 of all measured postural muscles. The results of between subjects' effects of stimulus velocity on APAs onset time and magnitude of postural muscles are shown in Table 2.

Pairwise comparison of the main effects of the stimulus velocity showed that when confronted with slow velocity stimulus than fast velocity stimulus, APAs onset time of RA (72.05±2.643 ms), ES (71.1±1.442 ms), RF (72.25±2.191 ms), BF (69.45±1.853 ms), TA (90.6±3.013 ms), GA (70.9±1.369 ms) muscles significantly start earlier in time and accordingly had higher APAs magnitude (0.54±0.48, 0.59±0.24, 0.27±.0.037, 0.39±0.035, 0.57±0.04, 0.31±0.041, respectively). Conversely, in situation of fast stimulus velocity, onset time of APAs of RA (35.3±2.643 ms), ES (19±1.442 ms), RF (26.75±2.191 ms), BF (42.65±1.853 ms), TA (26.75±3.013 ms), GA (23.7±1.369 ms) muscles shifted toward the beginning of main movement and had lower magnitude (0.36±0.48, 0.24±0.24, 0.12±.0.037, 0.26±0.035, 0.19±0.04, 0.12±0.041, respectively). EMG traces for one representative subject is presented in Figure 2.

3.3. *Effects of expertise on APA*

The results of two-way MANOVA showed that, based on different levels of expertise, there was a statistically significant difference in APAs magnitude, $F_{(6, 31)}$ =29.07, *P* < 0.0005; Wilk's λ = 0.151, partial η2 =0.849, but no difference was seen in APAs onset time, $F_{(6, 31)}$ =1.83, *P* < 0.125; Wilk's λ = 0.738, partial η2 =0.262 of all measured postural muscles. Between subjects' effects of levels of expertise on APAs onset time and magnitude of postural muscles are shown in Table 1. Further analysis showed that skilled player had higher APAs magnitude in GA, BF and ES muscles than novice player. The mean difference of APAs magnitude between skilled and novice player in BF, GA and ES muscles were 0.169±0.05, *P*=0.002; 0.136±0.05, *P*= 0.011 and 0.256±0.026, *P*< 0.0005 respectively (Figure 3).

3.4. *COP data*

The results of two-way MANOVA with two independent variables of temporal pressure (fast and slow stimulus) and levels of expertise (skilled and novice) and depended variables of COP parameters showed that there was a statistically significant difference in peak, velocity and RMS of COP excursion in AP direction based on different levels of expertise, F (3, 34) =35.578, P < 0.0005; Wilk's λ = 0.242, partial η2 =0.758 and different stimulus velocity F (3, 34) =119.108, P < 0.0005; Wilk's λ = 0.087, partial η2 =0.913. The results of between subjects' effects of stimulus velocity and levels of expertise are shown in Table 3.

Results of main effects showed that peak and velocity, and RMS of COP excursion in AP direction were higher in novice player than skilled counterparts. Also, peak COP excursion in AP direction were higher in slow than fast stimulus situation, however velocity and RMS of COP excursion was higher in fast than slow velocity situation (Figure 4).

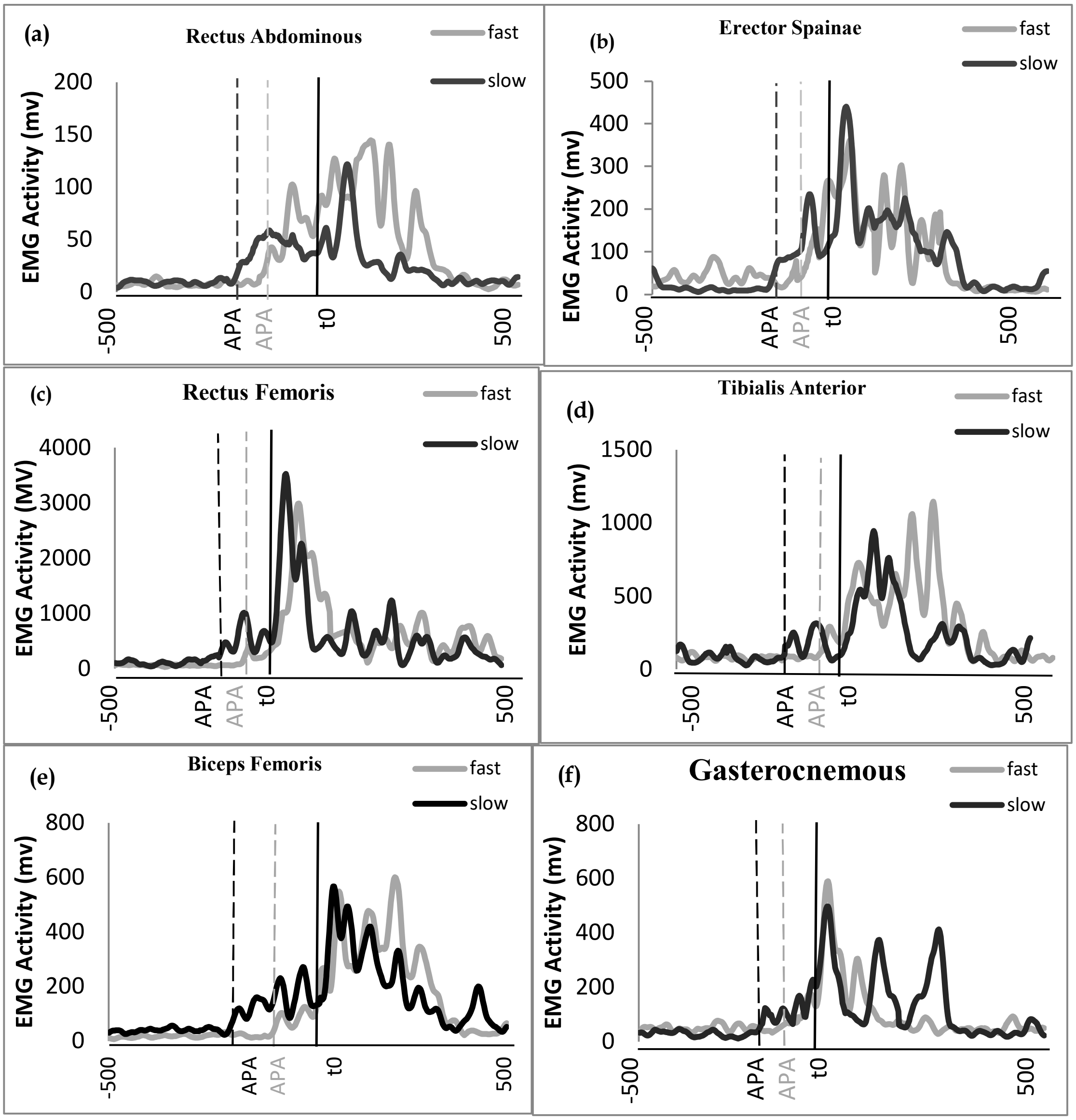

Figure 2. Typical EMG pattern of postural muscles averaged across trials by a representative subject. The black vertical dashed line shows the onset of APA in Slow stimulus situation. The grey vertical dashed line shows the onset of APA in Fast stimulus situation. The black vertical line shows the start of main movement (t_0).

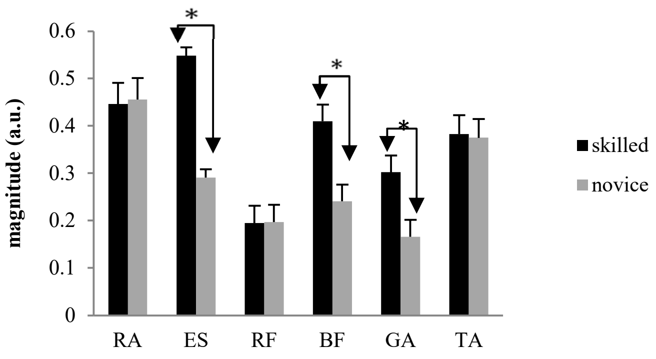

Figure 3. Postural muscles' APAs magnitude and standard error of skilled and novice players, averaged across trials. Dorsal postural muscles show significant differences between skilled and novice players. *Shows significant difference.

Table 3. Results of MANOVA test for parameters of COP data.

Parameter of COP Excursion	Levels of expertise			Stimulus velocity		
	F (1,36)	P	partial η2	F(1,36)	P	partial η2
Peak (AP)	26.067	< 0.0005*	0.420	85.525	< 0.0005*	0.704
Velocity (AP)	8.033	0.007*	0.182	104.354	< 0.0005*	0.744
RMS (AP)	58.086	< 0.0005*	0.617	265.722	< 0.0005*	0.881

Note: RMS= Root Mean Square. *Shows significant difference.

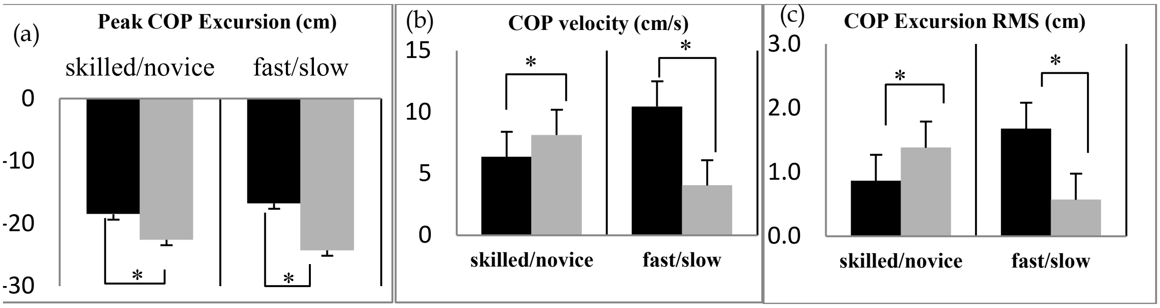

Figure 4. Demonstrates the peak, velocity and RMS differences of COP excursion (with standard error) between skilled/novice players and between fast/slow stimulus conditions. *Shows significant difference.

4. Discussion and Conclusion

Present study is designed to verify whether the time available for movement preparation modulates APAs-main movement coordination and determine whether this coordination is specific through different levels of expertise in performing the task. For manipulating the temporal pressure, the CAT task with fast and slow stimulus velocity was presented and participants responded to these stimuli while EMG and force plate data were recorded. In general, we can infer that the APAs-main movement coordination is control under dual parallel control and also there are greater links between characteristics of the APAs and parameters of ongoing task than predetermined mode of control achieved by previous experiences. This general conclusion is in line with (Slijper et al., 2002).

4.1. Effect of stimulus velocity on APA

The results showed that APAs occurred earlier and had greater magnitude when stimulus velocity was slow and in fast stimulus velocity situation the APAs onset time shifted toward the beginning of main movement and therefore had lower magnitude. However, it is hard to relate the greater magnitude of APA to the effect of stimulus velocity. The reason is that muscles' co-contraction led to associated increase in burst of all muscle EMGs. Since EMG integrals is calculated from beginning of APA to t_0 (Slijper & Latash, 2004), the earlier APA onset time led to greater APA magnitude. Therefore, the effect of stimulus velocity is mainly on APA on set time. Temporal shifts in EMG activity followed by the different magnitude of the anticipatory COP displacement, velocity and variability, led to this conclusion that if greater time for motor preparation is available for CNS, the generated APAs is better fit for postural demands. This conclusion drawn due to the delay occurred between the EMG or COP activity onset and the main movement onset. Such coordination of APAs-main movement was also observed in relation to self-initiated fast arm movement (Aruin & Latash, 1995) or in reaction time condition (Cuisinier, Olivier, & Nougier, 2005; Slijper et al., 2002), and it was in line with the result of (Ilmane & Larue, 2011; Ilmane & LaRue, 2008). It was then suggested that the increase of the pre-motor time could explain the delaying and higher magnitude of the APAs (Chen et al., 2015). Accordingly, A possible reason for higher backward anticipatory COP peak, during slow stimulus velocity condition might be due to the increased baseline activity, early onset time and higher magnitude of APAs in slow velocity condition; that is, the CNS had more time to prepare the postural and main movement commands. So, increase in the backward anticipatory COP peak in slow stimulus situation is the CNS strategy to better counteract the perturbation of main movement. Therefore, Our results demonstrate independent initiation of APAs and main movement (Ilmane & Larue, 2011; Ilmane & LaRue, 2008; Slijper & Latash, 2004; Slijper et al., 2002) and in line with the duall parallel control model of APAs-main movement coordination (Massion, 1992).

4.2. Effect of expertise on APA

For Interpreting the behavioural differences observed between skilled and novice players, it was concluded that the decreases seen in anticipatory COP peak, velocity and variability (RMS) of APAs of skilled player were interpreted as skilled player has ability to anticipate body position change more effectively than novice player. The same conclusion was driven by (Thompson, Badache, Cale, Behera, & Zhang, 2017) in differentiating athletes and non-athletes and by (Liang et al., 2019) in comparing athletes of contact sports and less contact sport.

In differentiating APA according to effect of expertise, with the same method of EMG integral calculation and almost similar APA onset time, magnitude of APA of dorsal muscles were greater for skilled players than novice ones. Therefore, one possible reason might be due to the experts' strategy to counteract perturbation. Anticipatory dorsal muscle activity of skilled player is likely to contribute to their improved stability than novice player to compensate for the lower backward anticipatory COP peak of skilled player. It is in line with previous study stated that skilled player had more elaborate postural strategies (Paillard, 2019). Also, researchers formulated a general hypothesis that APAs magnitude is related to the perceived postural stability and possible range of COP shift (Slijper & Latash, 2004). Possibly the perceived postural stability is different between skilled and novice players and higher amplitude of dorsal muscles in skilled player might be an anticipatory postural strategy of skilled player to reduce perturbation. That might also be due to some internal model that skilled player developed during long term adaptation to this task, which needs further investigation.

The similarity of APAs' onset time for skilled and novice player shows that the modulation of the APAs-main movement coordination is according to the perturbation of the oncoming action (Aruin, 2003; Slijper et al., 2002). Also, results show that the CNS uses the available time for motor command preparation to modulate APAs-main movement coordination to better counteract the expected perturbation (Ilmane & Larue, 2011; Shiratori & Latash, 2000). So, it seems that expertise does not have much effect on this modulation. Furthermore, these results reflect the existence of close links between characteristics of APAs and parameters of the action that induce postural perturbation (Slijper et al., 2002), not a pre-determined APAs pattern which is generated by long term practice and experience. Altogether, the available time to prepare the postural commands is affected by the characteristics of the current task (in this study was stimulus velocity) and not by levels of expertise. These results are also in line with hypothesis that onset time and magnitude of APA is task dependent but subjects might show some task-invariant patterns of postural muscles activation (Smith, Ignasiak, & Jacobs, 2020) and the previous statement that although individual differences (in this study was expertise) are important for balance control but did not significantly predicted changes in APA (Zaback, Cleworth, Carpenter, & Adkin, 2015)

Also, the similarity in onset time of APAs between skilled and novice players might be related to their central set. Central set is the immediate pre-selection of the postural muscles and the manner of preparing for the movement according to their ability to contribute stability (Horak, Diener, & Nashner, 1989). It is documented that the central set is specific to the task and does not affect EMG onset latencies (Shumway-Cook & Woollacott, 2007).

Participant with higher level of expertise, although had same APA onset time with novice counterparts, more magnitude of dorsal muscles was observed for them, which might lead to more anticipatory backward peak COP excursion. They also showed higher co-contraction of joints muscle couplings with lower COP velocity and RMS. These results are in line with previous studies that athletes with higher level of expertise had better postural performance than novice one (Liang et al., 2019; Popa et al., 2008; Powell & Williams III, 2015).

We conclude that available time for movement preparation had an effect on APAs-main movement coordination. This available time influenced by characteristics of ongoing task, which cause perturbation. Although some differences seen between skilled and novice player especially the higher magnitude of dorsal muscles of skilled players, the similarity in onset time of APAs of skilled and novice player does not let certain conclusion about the effect of expertise in modulation of APAs- main movement coordination in respect to their onset time and associated APA magnitude. Maybe the effect of expertise would be seen more in feedback postural control that is compensatory postural adjustment.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Akpinar, S., Devrilmez, E., & Kirazci, S. (2012). Coincidence-Anticipation Timing Requirements are Different in Racket Sports. *Perceptual and Motor Skills*, *115*(2), 1–13. https://doi.org/10.2466/30.25.27.PMS.115.5.ISSN

Aruin, A. S. (2003). The effect of changes in the body configuration on anticipatory postural adjustments. *Motor Control*, *7*(3), 264–277. https://doi.org/10.1123/mcj.7.3.264

Aruin, A. S., Kanekar, N., Lee, Y.-J., & Ganesan, M. (2015). Enhancement of anticipatory postural adjustments in older adults as a result of a single session of ball throwing exercise. *Experimental Brain Research*, *233*(2), 649–655. https://doi.org/10.1007/s00221-014-4144-1

Aruin, A. S., & Latash, M. L. (1995). The role of motor action in anticipatory postural adjustments studied with self-induced and externally triggered perturbations. *Experimental Brain Research*, *106*(2), 291–300. https://doi.org/10.1007/BF00241125

Chen, B., Lee, Y. J., & Aruin, A. S. (2015). Anticipatory and compensatory postural adjustments in conditions of body asymmetry induced by holding an object. *Experimental Brain Research*, *233*(11), 3087–3096. https://doi.org/10.1007/s00221-015-4377-7

Cuisinier, R., Olivier, I., & Nougier, V. (2005). Effects of foreperiod duration on anticipatory postural adjustments: Determination of an optimal preparation in standing and sitting for a raising arm movement. *Brain Research Bulletin*, *66*(2), 163–170. https://doi.org/10.1016/j.brainresbull.2005.04.010

Day, S. (2002). Important factors in surface EMG measurement. *Bortec Biomedical Ltd Publishers*, 1–17.

Ekstrom, R. A., Donatelli, R. A., & Carp, K. C. (2007). Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *Journal of Orthopaedic & Sports Physical Therapy*, *37*(12), 754–762.

Galgon, A. K., Shewokis, P. A., & Tucker, C. A. (2010). Changes in standing postural control during acquisition of a sequential reaching task. *Gait & Posture*, *31*(2), 265–271. https://doi.org/10.1016/j.gaitpost.2009.11.002

Hardie, R., Haskew, R., Harris, J., & Hughes, G. (2015). The effects of bag style on muscle activity of the trapezius, erector spinae and latissimus dorsi during walking in female university students. *Journal of Human Kinetics*, *45*(1), 39–47.

Horak, F. B., Diener, H. C., & Nashner, L. M. (1989). Influence of central set on human postural responses. *Journal of Neurophysiology*, *62*(4), 841–853. https://doi.org/10.1152/jn.1989.62.4.841

Ilmane, N., & Larue, J. (2011). Modulation of Anticipatory Postural Adjustments in the Anticipation-Coincidence Task. *Journal of Motor Behavior*, *43*(4), 333–343. https://doi.org/10.1080/00222895.2011.594819

Ilmane, N., & LaRue, J. (2008). Modulation of anticipatory postural adjustments in a complex task under different temporal constraints. *Motor Control*, *12*(4), 330–347. https://doi.org/10.1123/mcj.12.4.330

Klous, M., Mikulic, P., & Latash, M. L. (2011). Two aspects of feedforward postural control: anticipatory postural adjustments and anticipatory synergy adjustments. *Journal of Neurophysiology*, *105*, 2275–2288. https://doi.org/10.1152/jn.00665.2010

Klous, M., Mikulic, P., & Latash, M. L. (2012). Early postural adjustments in preparation to whole-body voluntary sway. *Journal of Electromyography and Kinesiology*, *22*(1), 110–116.

Krishnan, V., Latash, M. L., & Aruin, A. S. (2012). Early and late components of feed-forward postural adjustments to predictable perturbations. *Clinical Neurophysiology*. https://doi.org/10.1016/j.clinph.2011.09.014

Liang, Y., Hiley, M., & Kanosue, K. (2019). The effect of contact sport expertise on postural control. *PloS One*, *14*(2). https://doi.org/10.1371/journal.pone.0212334

Massion, J. (1992). Movement, posture and equilibrium: Interaction and coordination. *Progress in Neurobiology*. https://doi.org/10.1016/0301-0082(92)90034-C

Merletti, R. (2000). Surface electromyography: The SENIAM project. *European Journal of Physical and Rehabilitation Medicine*, *36*(4), 167.

Mohapatra, S., Krishnan, V., & Aruin, A. S. (2012). Postural control in response to an external perturbation: effect of altered proprioceptive information. *Experimental Brain Research*, *217*(2), 197–208. https://doi.org/10.1007/s00221-011-2986-3

Paillard, T. (2019). Relationship between sport expertise and postural skills. *Frontiers in Psychology*, *10*, 1428. https://doi.org/10.3389/fpsyg.2019.01428

Popa, T., Bonifazi, M., Della Volpe, R., Rossi, A., & Mazzocchio, R. (2008). Anticipatory control of impending postural perturbation in elite springboard divers. *European Journal of Applied Physiology*, *104*(6), 1007–1011. https://doi.org/10.1007/s00421-008-0856-x

Powell, D. W., & Williams III, D. S. B. (2015). Athletes trained using stable compared to unstable surfaces exhibit distinct postural control profiles when assessed by traditional and nonlinear measures. *Human Movement Science*, *44*, 73–80. https://doi.org/10.1016/j.humov.2015.08.013

Ramezanzadeh, H. (2011). *The Effect of Practice Arrangement (Contextual Interference) with Constant, Increasing and Decreasing Speeds on Acquisition, Retention and Transfer of Coincidence Anticipation Tasks*. Shahid Beheshty University.

Rashid, M. R., Ahmad, I. N., Haron, R., & Adnan, R. (2012). Treatment effectiveness of continuous passive motion machine during post-operative treatment of anterior cruciate ligament patients. *2012 IEEE Symposium on Humanities, Science and*

Engineering Research, 469–473. IEEE.

Saito, H., Yamanaka, M., Kasahara, S., & Fukushima, J. (2014). Relationship between improvements in motor performance and changes in anticipatory postural adjustments during whole-body reaching training. *Human Movement Science*, *37*, 69–86. https://doi.org/10.1016/j.humov.2014.07.001

Schmidt, R. A. (1988). *Motor Control and Learning 5th Edition*. Human kinetics.

Sheppard, A., & Li, F. X. (2007). Expertise and the control of interception in table tennis. *European Journal of Sport Science*, *7*(4), 213–222. https://doi.org/10.1080/17461390701718505

Shin, W. T. (2019). *Effects of Boxing Training on Anticipatory Postural Adjustments* (Miami University). Miami University. https://doi.org/http://rave.ohiolink.edu/etdc/view?acc_num=miami15559579258238

Shiratori, T., & Latash, M. (2000). The roles of proximal and distal muscles in anticipatory postural adjustments under asymmetrical perturbations and during standing on rollerskates. *Clinical Neurophysiology*, *111*(4), 613–623. https://doi.org/10.1016/S1388-2457(99)00300-4

Shumway-Cook, A., & Woollacott, M. H. (2007). *Motor Control: Translating Research Into Clinical Practice*. Lippincott Williams & Wilkins. Retrieved from https://books.google.com/books?id=BJcL3enz3xMC

Slijper, H., & Latash, M. L. (2004). The effects of muscle vibration on anticipatory postural adjustments. *Brain Research*, *1015*(1–2), 57–72. https://doi.org/10.1016/j.brainres.2004.04.054

Slijper, H., Latash, M. L., & Mordkoff, J. T. (2002). Anticipatory postural adjustments under simple and choice reaction time conditions. *Brain Research*, *924*, 184–197. https://doi.org/10.1016/S0006-8993(01)03233-4

Smith, J. A., Ignasiak, N. K., & Jacobs, J. V. (2020). Task-invariance and reliability of anticipatory postural adjustments in healthy young adults. *Gait & Posture*, *76*, 396–402. https://doi.org/10.1016/j.gaitpost.2020.01.003

Steenhuis, R. E., & Bryden, M. P. (1989). Different dimensions of hand preference that relate to skilled and unskilled activities. *Cortex*, *25*(2), 289–304. https://doi.org/10.1016/S0010-9452(89)80044-9

Thompson, L. A., Badache, M., Cale, S., Behera, L., & Zhang, N. (2017). Balance performance as observed by center-of-pressure parameter characteristics in male soccer athletes and non-athletes. *Sports*, *5*(4), 86. https://doi.org/10.3390/sports5040086

Zaback, M., Cleworth, T. W., Carpenter, M. G., & Adkin, A. L. (2015). Personality traits and individual differences predict threat-induced changes in postural control. *Human Movement Science*, *40*, 393–409. https://doi.org/10.1016/j.humov.2015.01.015

Zhao, Z., Watanabe, K., Asaka, T., & Wang, Y. (2020). Postural control in preparation to a step during support surface perturbation. *Research in Sports Medicine*, 1–6. https://doi.org/10.1080/15438627.2020.1745802