ULTRASONIC MONITORING FOR THE EVALUATION OF CONDITIONING BY TRAINING SESSION FOR ATHLETES

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Non-intrusive ultrasonic detection scheme has been implemented to monitor and quantify the loading effect of training sessions on athletes. The detection is obtained along a line between two acoustic transducers with similar size and shape as stick-on electrodes. All the data is derived from the transmission time-of-flight of the ultrasonic chirp signal passing through the muscle and the ultrasonic force sensor. Muscle dynamics and force generated due to maximum isometric contraction was synchronously detected with the aid of an arbitrary function generator and a two channels transient recorder. At least 16 performance deciding parameters of athletes are quantified. The achieved spatial and temporal resolutions are ± 0.01 mm and 0.01 ms respectively. Detected movement reaction time could be used as a potential indicator to identify false-start in athletics, swimming and other necessary fields.

KEYWORDS: Ultrasound transmission in-vivo, inter-muscular force, muscular endurance, movement reaction time, ultrasonic force sensor.

INTRODUCTION: On-field performance monitoring is of high importance in sports and similar activities. Regular monitoring of the key dynamic and metabolic functions is essential to achieve dominant athletic performance. Several ultrasonic setups for body motion control have been proposed so far (patents US 5 220 922, DE 4214523 and US 7 041 062 B2). An ultrasonic monitoring scheme employing chirp technology for high resolution and rapid monitoring of the change of muscle extension was developed (Zakir Hossain et al., 2008). The system has also been used to monitor the sonic velocity variation under voluntarily activated muscle (Zakir Hossain et al., 2009). In this scheme an arbitrary function generator produces a chirped ultrasonic wave, that passing through the observed muscle. The transit signal is observed with a synchronized transient recorder. Subsequently the time-of-flight (TOF) is determined with the implemented software. Subsequent evaluation including modeling allows the determination of parameters relevant for training like: movement reaction time, muscle endurance, muscle force and power, rate of energy expenditure and other parameters of use for the optimization of training process.

METHOD: Six healthy athletes (three boys and three girls) were selected from a training camp. Their average age was 11.00 ± 0.33 and BMI 18.00 ± 0.29. The data were recorded before and after a daylong exhaustive training session. The training load was designed and organized by the professional trainer.

Flexion of the knee joint was restricted by an ultrasonic force sensor to monitor gastrocnemious muscle force and dynamics as well, for maximum isometric contraction (figure 1, left). Action was initiated by a sound beep at zero time. Monitored athletes pull back the sonic force sensor with maximum effort and hold as long as possible. The action ended with sudden withdrawal of the maximum pulling force. The position of the foot and joint angle was ensured unchanged with a suitable arrangement.
Evaluation of the collected data was performed in real time by dedicated LabVIEW software. Inflection points and conventional fitting are employed to quantify the performance variables of the monitored gastrocnemius muscle. The time from the onset of the audio stimulation to the onset of the muscle movement is interpreted as the athlete movement reaction time. Figure 1, graph (right) depicted different phases observed from the monitoring. From these, parameters relating to the athlete’s muscle dynamics and energy expenditure can be obtained.

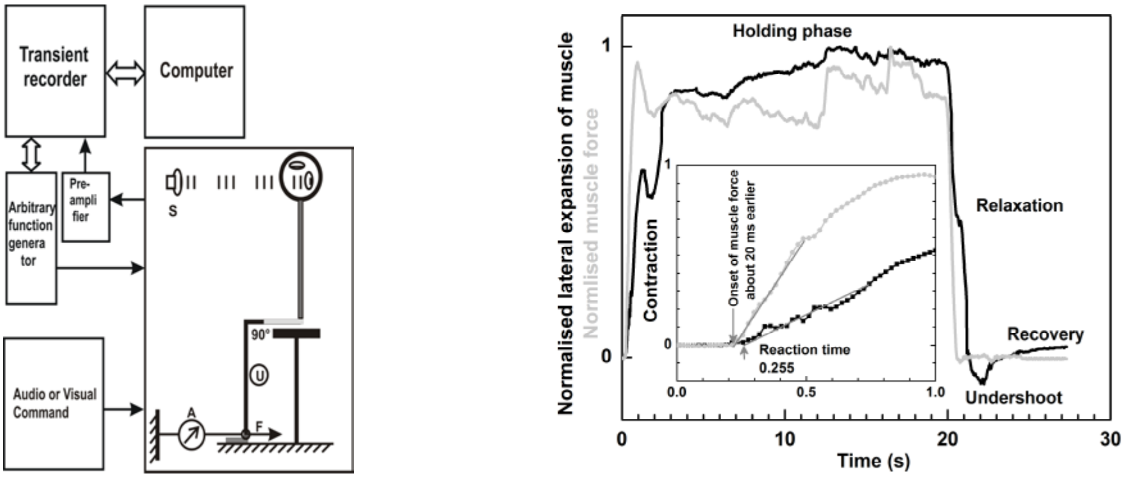

Figure 1. The schematic diagram for data acquisition setups (left) for synchronized monitoring of the muscle force and the muscle dynamics. S: audio signal, U: ultrasonic monitoring, F: delivered force, and A: ultrasonic force sensor.
Right: Graph of the obtained data. Black: muscle movement; grey: the exerted force. The inset is the analyzed transients graph demonstrating the scheme for the determination of the reaction time.

RESULTS: As illustrated in figure 1 (right) from respective readings and fits a movement reaction time of 255 ms was observed. Other observed: the maximum lateral muscle deformation 12.6 mm with variations within ± 2.1 mm, the holding phase of 18.7 s, the slope of the holding phase was about 1.1 mm s^{-1}. For the monitored muscle a contraction and relaxation speed of 3.31 mm s^{-1} and 7.76 mm s^{-1} respectively was determined. A fit to the recovery phase allowed the determination of a time constant $\tau = 2.27$ s for recovery from the initiated action, which was a quantitative measure for the ability to recover from the post isometric tetanus effect. The muscle force onset was found approximately 20ms earlier than the muscle movement onset. The observed 17% post isometric undershoot represents an example for a scientifically relevant result related to post isometric stretch (Brenner 1990 and Alter 1996).

The figure 2 below is the graphical representation of pre and post physical loading data of an athlete. From the monitored lateral muscle dynamics and force-applied following quantitative results were obtained:

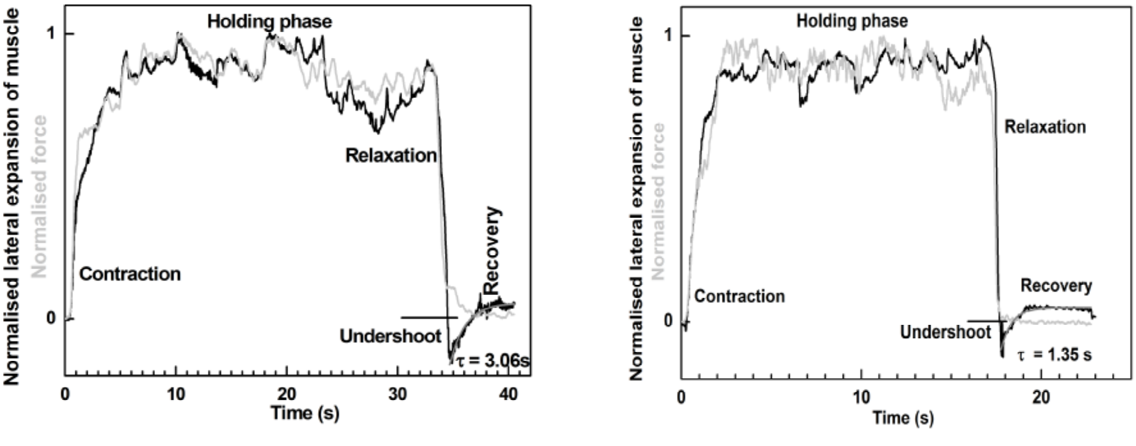

Figure 2. Displayed are the transients for muscle performance prior to (left) and after tennis training load (right) together with the applied force variation of the monitored muscle. An interpretation of the different phases is indicated.

The movement reaction time for pre- and post-physical loading were found to be 357 ms and 422 ms respectively. Contraction speed of 2.38 m s^{-1} and 2.59 m s^{-1}. A comparatively stable slope (figure 2) of 0.02 mm s^{-1} and 0.03 mm s^{-1}, were quantified from the respective holding phases. Relaxation speed 10 mm / s and 7 mm / s and the novel parameter undershoot

19.25% and 16.7% ware observed respectively for pre and post physical loading curves. Recovery time constant 3.06 s and 1.35 s were observed from the muscle dynamics curves of the monitored athlete.

Comparative results of six athletes for pre- and post-physical loading are presented below: The values are normalized to the individual initial performance to show the day long physical loading effect on the different performance deciding parameters of the monitored athletes.

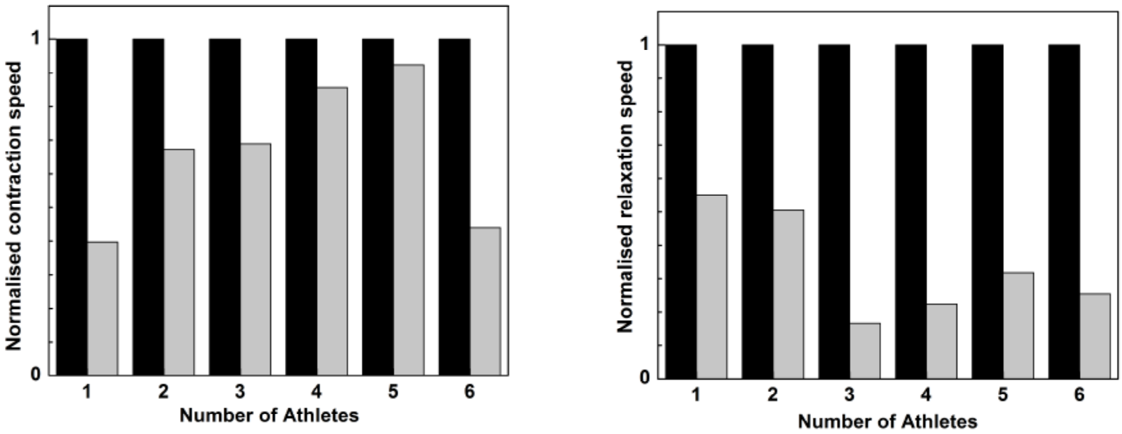

Figure 3. Displayed are the contraction (left) and relaxation (right) speed of the monitored gastrocnemius muscle for 6 different athletes. The values are normalized to the individual initial performance. The results relate to pre- (black) and post-physical loading monitoring (grey).

The bar heights of post loading muscle contraction and relaxation are comparatively lower in comparison to the individual initial i.e. pre-loading values (figure 3). That indicates muscle contraction and relaxation efficiency after a daylong training have been reduced. The holding time for athlete 6 drops substantially and athlete 3 shows an increase (figure 4, left). On the other hand the holding slopes (figure 4, right) dropped faster after the physical loading. For athletes 1, 4 and 5, holding slope droppings were substantially faster following the training load.

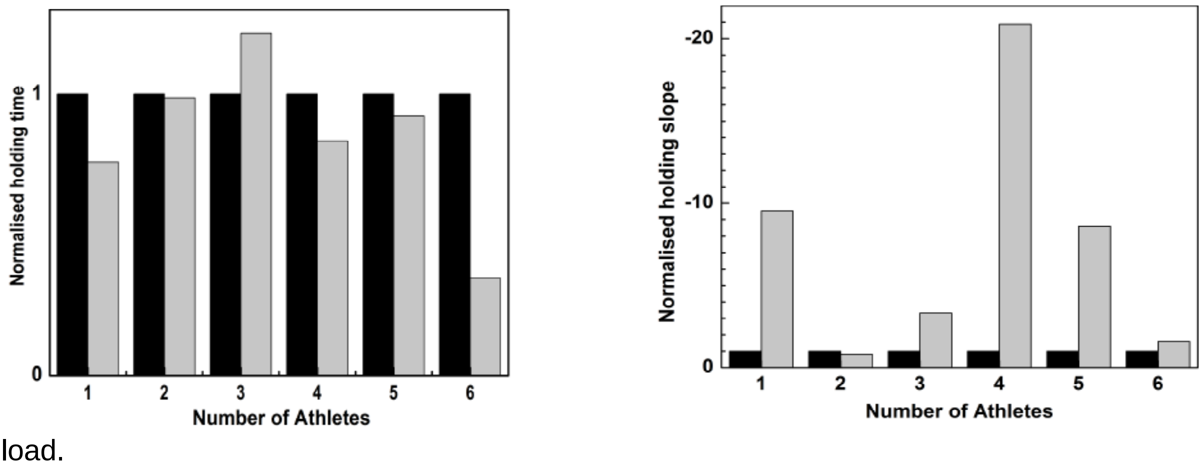

Figure 4. Maximum holding time (left) and holding slope (right) for 6 different athletes prior (black) and post (grey) loading. The values are normalized to the individual initial performance.

The quantification of the holding slope for maximal isometric contraction leads to the result, that athlete 1, 4, and 5's slope falls between 10 and 21 times faster after loading. That is substantially different than observed for the other three. It is clearly indicated that the three mentioned athletes are not conditioned for endurance, since the initially observed already comparatively large holding slope dropped substantially after exercise.

The muscle force generated due to maximum isometric contraction shows deterioration after the physical loading (figure 5, left). Except for athlete 6 the muscle force shows about 20 % to 40 % deterioration.

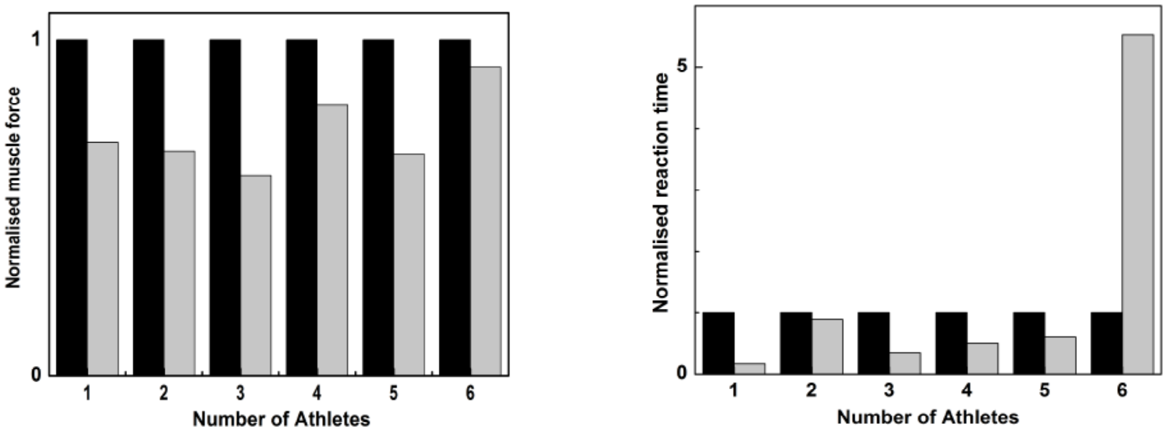

Figure 5. Maximum muscle force (left) and movement reaction time(right) for 6 different athletes prior (black) and post (grey) loading. The values are normalized to the individual initial performance.

The movement reaction time for the monitored athletes is displayed in figure 5 (right). Only athlete 6 shows a significant variation of the movement reaction time after exhaustion.

CONCLUSION AND DISCUSSION: The developed ultrasonic detection scheme is suitable for monitoring of isometric contraction which cannot be observed by high speed camera observation. The additional delay from the nerve signal to the actual movement is included which is not the case for EMG monitoring. The detection scheme is non-invasive, easily accessible and cost effective. Quantitative findings ensure its applicability in on-line monitoring of so far unobserved parameters. These include muscle contraction speed, relaxation speed, contraction impulse, relaxation impulse, slope and steadiness of the holding phase, stress, muscular endurance et cetera. The undershoot during recovery from the tetanus effect was observed for the first time in this study. Stride-length, stride-frequency, ground contact time, toe-off time, supporting phase, flying phase of running, jumping and walking are also amiable with this system. The achieved spatial and temporal resolution proves its applicability in monitoring all possible mammalian motion. This detection scheme offers easy access to assess the imparted loading effect on the athletes. Regular monitoring of this kind will help to formulate and regulate the training load to ensure maximum development of athlete’s performance.

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