

Research article

RELIABILITY AND VALIDITY TESTING OF AN ARCHERY CHRONOMETER

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ABSTRACT

Keeping the arrow velocity constant during consecutive shots and responding to “clicker’s fall” are considered to be an important feature of archery performance. A specially designed device called an *archery chronometer* was developed to measure the reaction time of an archer to clicker’s fall, arrow velocity, and external factors that may affect arrow velocity. The purposes of this study were to test (1) the validity of Clicker Reaction Time (CRT) measurer, and (2) the reliability of CRT in accordance with the Flying Time (FT)/Average Speed (AS), temperature (TEMP), wind speed (WS) and wind direction (WD) measurements. 20 elite archers participated in this study. The Reaction Time (RT), which was derived from EMG values and CRT from the archery chronometer were correlated to test the validity of the CRT measurer. The test re-test method was applied to test the reliability of archery chronometer. CRT scores were related with RT scores ($r = .787$, $p < 0.01$). The archery chronometer was valid in terms of predicting reaction time. The device was found to be reliable in measuring CRT, AS, FT, WS, WD, and TEMP. It was concluded that archery chronometer could be used for technical evaluation and enhancing ones shooting technique in archery.

KEY WORDS: Archery, electromyography (EMG), reaction time, muscular analysis.

INTRODUCTION

Archery can be described as a comparatively static sport requiring strength and endurance of the upper body, in particular the forearm and shoulder girdle (Mann and Littke, 1989). Skill in archery is defined as the ability to shoot an arrow to a given target in a certain time span with accuracy (Leroyer et al., 1993). The discipline is described as a six-phase movement in terms of shooting technique by Nishizono et al. (1987); Bow Hold, Drawing, Full Draw, Aiming, Release, and Follow-through. Each of these phases represents a stable sequence of movements and is ideal for studying the motor control and skill acquired during this voluntary kinematical process. However, Pekalski (1990) differentiated shooting technique from bow-arrow-archer interaction. He stated the paramount importance of the movement of the arrow in archery.

He divided arrow movement into two phases: (1) the interaction between an arrow and archer-bow subsystem that lasts from the moment of releasing the bowstring until the arrow loses contact with the bow and the bowstring. (2) Ballistic flight: This lasts from the end of phase 1 until the arrow hits the target.

An important feature of archery is keeping the arrow velocity constant during consecutive shots (Marconnet and Komi, 1987). The arrow velocity can be affected from the shooting technique (release and/or follow through phases) of the archer, weather conditions (e.g. wind, rain, and heat) and any technical dysfunction of the bow and/or arrows. Having different arrow velocities necessitate examining the shooting technique of the archer, weather conditions, and equipment. A coach or the archer can standardize the equipment factors by having exactly the same size and weight arrows and

using a device called “clicker” to fix the drawing weight of the bow constant.

The bowstring is released when an auditory stimulus is received from the clicker. A standard drawing length and release can be obtained using this device (Ertan et al., 2003; Ertan et al., 2004). The archer will not be able to control the drawing length and weight of the bow if s/he does not respond to the stimulus from the clicker as quickly as possible. Losing the control of the drawing length of the arrow and the weight of the bow will cause a difference in the release weight of the bowstring and flying velocity of the arrow. Thus, having a quick reaction to the clicker’s fall (sound) is directly related with the performance of the archer (Ertan et al., 1996). So, Reaction Time (RT) is used to classify the archers as elite, intermediate or beginners. Elite archers (Olympic and world championship medalists) have displayed better RT values than that of intermediate and beginner archers (Landers et al., 1986). However, their measurements were not during archery shooting. They have given an auditory stimulus to their subjects and the subjects were supposed to respond to this stimulus as quickly as possible by pressing a button, which stops the counting machine. As long as their measurement was more than a RT measurement (Schmidt, 1999), it has given an idea about the importance of the response timing in differentiating the archers in different performance levels.

A device called “an archery chronometer”, which is appropriate to the field settings in archery, was developed to measure (1) the reaction time of an archer to the clicker’s fall (Clicker Reaction Time: CRT), (2) Flying Time (FT) and/or Average Speed (AS) of the arrow over a given distance, (3) Wind Speed (WS) and Direction (WD), and (4) Temperature (TEMP). The device is developed both to constitute a baseline from a different aspect for archery performance prediction and to analyze the relations connected to the equipment parameters and archer’s shooting technique (Ertan et al., 1996).

It was hypothesized that (i) archery chronometer will make valid CRT measurement compared to the EMG measurement of forearm finger extensor muscles and (ii) reliable (reproducible) CRT, Flying Time (FT)/Average Speed (AS), temperature (TEMP), wind speed (WS) and direction (WD) measurements. The purposes of the study are;

1. To examine the validity of CRT measurement device.
2. To examine the reliability of the Flying Time (FT) / Average Speed (AS), temperature

(TEMP), wind speed (WS) and direction (WD) measurements using the CRT device.

METHODS

Participants

Twenty elite archers (10 women, 10 men) were involved in this study. The subject group consisted of the Turkish national team archers and candidate archers for the team. The subjects were recruited during a preparation camp that was held just before an international competition. 10 of the subjects were junior archers. Information on the participants including the Federation Internationale de Tir a l’Arc (FITA) scores, years of archery experience, and ages are presented in Table 1. Written informed consent was obtained from all of the subjects and from their guardians/parents for those who were below 18 years old before participation to the study.

Table 1. Subjects’ FITA scores, years of archery experience, and ages. Data are means (\pm SD).

Variables	Archers	
	Men (n = 10)	Women (n = 10)
Age	19.8 (5.2)	20.7 (3.4)
FITA Scores	1235 (67)	1241 (72)
Years of Training	6.5 (.8)	7 (1.1)

Procedures

Validity testing of CRT

Each subject participated in a single test session in the Biomechanics Laboratory, where the EMG activity of flexor digitorum superficialis and extensor digitorum muscles were quantified and CRT was measured. The EMG and CRT measurement methods were synchronized with each other. Archery chronometer was placed on the bow handle, and then a switch was attached under the clicker. These two systems were isolated from each other in order to shun cross-talk effect among measurement devices. The subjects shot 12 arrows for validity testing of “Clicker Reaction Time Measurer” in the laboratory.

Reliability testing of archery chronometer

Two trials were made for reliability testing of archery chronometer for CRT, FT/AS, WS, WD, and TEMP measurement methods; second one was made one week later than that of the first one (test-retest approach). Subjects shot 12 arrows for first and second trials from 70 m in an archery field. These two measurements were compared with each other to examine the test-retest reliability of the device for each of the sub-measurement methods in it. The

subjects were the same for both validity and reliability testing.

Archery chronometer

A specially designed device called an archery chronometer, which measures (1) CRT, (2) FT/AS, (3) TEMP and (4) WS and WD, was developed by Ertan et al. (1996). This device (Prosport TMR ESC 3100 Archery Chronometer) consists of four main components: (1) Screen, (2) CRT Measurement Device, (3) WS and WD Measurement Device, and (4) Vibration Sensor.



Figure 1. Placement of the CRT measurement device on the bow handle.

Screen

Seven different measurement results can concurrently be displayed on the screen of the archery chronometer: (1) CRT, (2) FT, (3) AS, (4) WS, (5) WD, (6) TEMP and (7) Battery Level (Bat). The device can make the measurement with 0.1 % second sensitivity and 0.01 % precision error. The screen is constructed with a LED panel, which is 32x128 resolutions in pixels, for indoor or outdoor use.



Figure 2. The placement of an arrow on the bow and reaching the final position in full draw and aiming phases.

Clicker reaction time measurement

A conductor metal, which has two heads, is placed under the clicker. One of the heads is attached under the clicker and the other is fixed on the bow handle.

In addition to this, a sensor, weighting 150 g and sensitive to metal, is placed on the bow handle 1.5 cm away from the clicker (Figure 1). The body of sensor, which has 24Vdc (Max) switching voltage and 1.0A switching current, is .22 in. and the diameter .14 in. During the CRT measurement, the arrow is placed under the clicker likewise all the archers do for each shot (Figure 2). The archer starts drawing the bowstring and reaches full draw (Figure 3).



Figure 3. The clicker falls from the tip point of the arrow.

The fall of the clicker brings the two heads together, which initiates the chronometer. As a response to the fall of the clicker, the archer releases the bowstring by opening the three-finger hook of the drawing hand. The arrow is pushed forward powerfully by the bowstring and the point of the arrow passes in front of the sensor with. The chronometer stops counting after sensing the metal tip point of the arrow (Figure 4). Ertan at al. (1996) defines this time interval as the CRT.

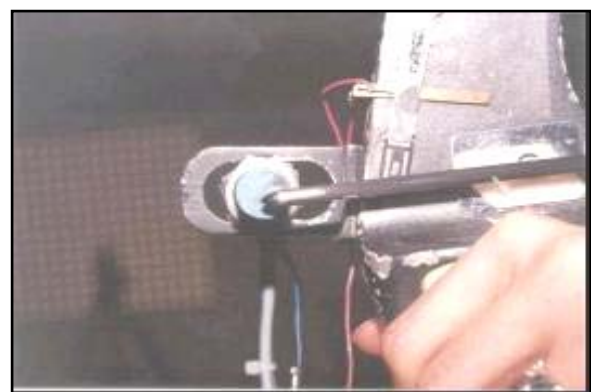


Figure 4. The tip point of the arrow passes in front of the sensor that is sensitive to metal.

Flying time and average speed measurement

As the metal tip point of the arrow passes in front of the sensor, the CRT measurement ends and the FT measurement starts (Figure 4). The arrow covers the shooting distance and hits the target causing a measurable vibration on it. A switch detects the vibration associated with the motion by arrow hit on

the target rather than the motion of arrow itself. The signal signifying the arrow's hit to the target is sent to the main unit telemetrically. The main unit stops the chronometer by receiving the telemetric impulse that is indicator of arrow hit. The FT and AS of the arrow can accurately be measured by this method for an identified distance according to the FITA rules (FITA, 2002). The following formula is used for calculation; $V = X/t$ formula [where; $V =$ speed ($\text{m}\cdot\text{sec}^{-1}$), $X =$ distance (m), and $t =$ time (sec)].

Wind speed and wind direction measurement

WS is measured as $\text{m}\cdot\text{sec}^{-1}$ and the WD is measured in degrees. The WS and WD measurers are attached to the main unit. It is placed at the midpoint of the shooting distance parallel to the shooting line. During the shot, the device continuously measures the WS and WD. As soon as the clicker snaps, the chronometer records the WS and WD. These parameters are displayed on the screen at the same time with the arrow release.

Data processing for validity testing of CRT measurement

Validity testing of the CRT was made under the laboratory conditions. Each subject participated in a single test session. Electromyographic activity of the Muscle flexor digitorum superficialis and Muscle extensor digitorum contractions were quantified by the use of OCTOPUS Analog Multiplexed cable Telemetry 8 channel device (AMT-8) concomitantly with the CRT measurements. Electrode sites were prepared by shaving, abrading and cleansing the area. Skin tack F55 surface electrodes, filled with conductive electrolyte were positioned longitudinally along each muscle. The distance between two electrodes was approximately 2 cm. The reference electrode was placed on the olecranon process of the ulna of the drawing arm. The mechanical switch was attached under the clicker to accurately measure both the point of the clicker fall on EMG recordings and initiate archery chronometer for CRT measurements.

Participants completed twelve successive shots. EMG recordings were made for 5 seconds; 2.5 seconds prior and 2.5 seconds after the clicker's fall. This period included the last seconds of the full draw, aiming, the first seconds of release and follow through phases. Absolute values of 2 seconds; one second before and one second after the clicker's impetus were processed to obtain rectified EMG data.

Reaction Time (RT) (Schmidt, 1991; Oxendine, 1968; Kerr, 1982; Latash, 1998) is defined as the time interval between the stimulus and the initiation of response. During a substantial part of the RT, the EMG is silent; indicating that the

command to move the finger had not yet reached the finger muscles (Schmidt, 1991). This latent period is the time the impulse is transmitted from the sensory organs to the central nervous system and then to the muscles (Latash, 1998). The muscle is activated in late RT, however; no movement occurs for 40 to 80 milliseconds. The interval from the stimulus to the first muscular contraction recorded in EMG is termed *premotor RT* and is thought to represent the central nervous system processes. The interval from the first change in EMG to finger movement is termed *motor RT* and represents the processes associated with the muscle itself. Movement time (MT) is usually defined as the interval from the initiation of the response (the end of RT) to the completion of the movement. The sum of RT and MT is termed as the *response time* (Figure 5).

The clicker's fall is defined as the stimulus. The peak latency of EMG data was considered as the RT in the current study. Thus, the time gap between stimulus (clicker's fall) and response (initiation of muscular activity) is decided. From the definitions given above, the initiation of muscular activity in the forearm muscles including latent period and contraction time (Vander et al., 1990) was considered to be the RT for the arrow release movement. Reaction times were obtained from the rectified EMG data for each shot of each subject (Figure 6). So, there were totally 240 RT scores for the whole subject group.

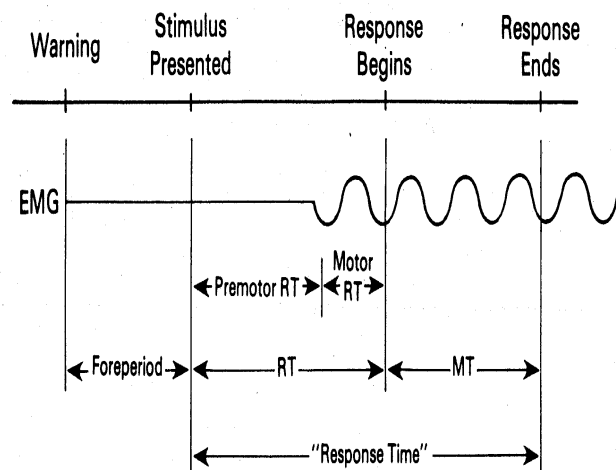


Figure 5. Critical events involved in the reaction time paradigm (RT: Reaction Time; MT: Movement Time; EMG: Electromyography). The upper trace is a hypothetical EMG record taken from the relevant muscle (Schmidt, 1999; pg: 28).

Data processing for reliability of archery chronometer

The reliability testing measurements were made in the archery field. Each of the subjects shot 12 arrows

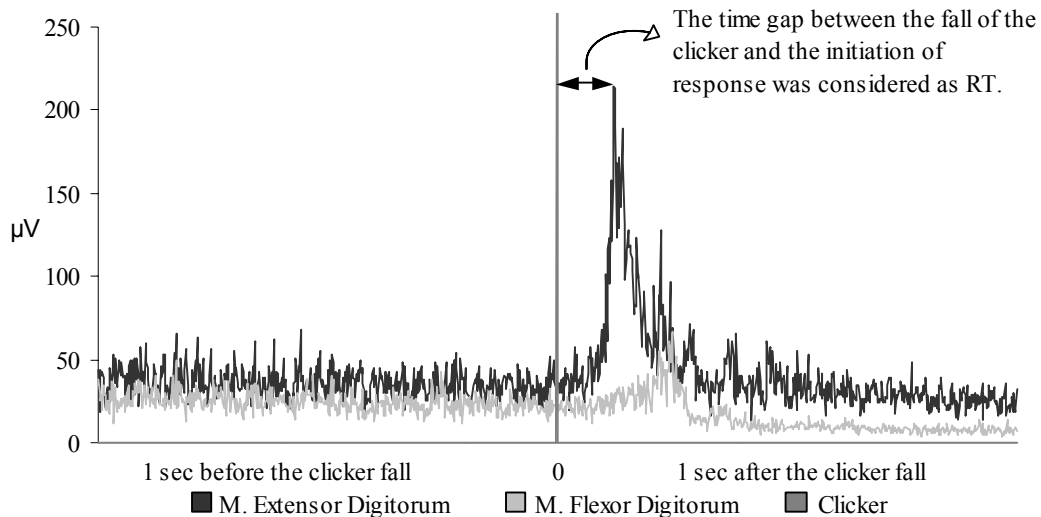


Figure 6. The calculation of reaction time from EMG data.

from 70 m. All the subjects were those who participated in the laboratory measurements for validity testing. Measurements were made in a suitable weather condition for the archery shooting (without rain and strong wind). A week later all measurements were repeated with the same subjects in the same shooting order and in the same weather conditions (without rain and strong wind).

Table 2. Descriptive statistics of Clicker Reaction Times (CRT) and EMG Reaction Times (RT) for 20 subjects' shots.

	Min	Max	Mean	SD (\pm)
CRT	.102	.502	.17743	.055
RT (by EMG)	.088	.342	.14622	.047

Statistical analysis

Descriptive statistics were applied to summarize the characteristics of the subjects. The mean CRT and RT scores of each archer's twelve shoots were correlated by the Pearson Correlation Coefficient test for the validity testing of CRT measurer. For reliability testing, the mean of each subject's twelve shoots was calculated and the data were analyzed with the Kolmogorov / Smirnov test. Reliability of the measurement of the archery chronometer over two sessions was estimated via interclass correlation coefficient (ICC). ICC model 3.1 was selected because of its appropriateness for testing test-retest reliability (Swanenburg et al., 2003). In addition to classical analysis of reliability using ICC, Bland and Altman plots were also used to gain more information on the reliability of measurements (Bland and Altman, 1986). Bland–Altman plots are used to show ranges for the repeatability of the measurements and they show the differences between paired observations against the mean value of the two observations. A wider scatter from the

zero difference line indicates a poorer reproducibility. The 95% limits of agreement are defined by ± 1.96 standard deviations of the data. We can use these limits of agreement to define whether changes in future field measurements are significant or whether they lie within the bounds of the variability of the measurement.

RESULTS

Validity results of CRT measurement device

The mean score for CRT was found to be higher than RT (Table 2). The difference between CRT and RT was statistically significant ($p = 0.027$). CRT scores were related to RT scores ($r = 0.787$, $p < 0.01$).

Table 3. Results of descriptive tests ($n = 20$). Data are means (\pm SD).

Variables		
Pair 1	CRT 1	.180 (.042)
	CRT 2	.179 (.039)
Pair 2	FT 1	1.290 (.030)
	FT 2	1.287 (.030)
Pair 3	AS 1	184.19 (4.54)
	AS 2	183.71 (4.40)
Pair 4	WS 1	.81 (.36)
	WS 2	.81 (.36)
Pair 5	WD 1	170.65 (5.25)
	WD 2	167.15 (6.17)
Pair 6	TEMP 1	23.45 (2.24)
	TEMP 2	22.65 (2.50)

Abbreviations: CRT = Clicker Reaction Time (msec), FT = Flying Time (sec), AS = Average Speed ($\text{km}\cdot\text{h}^{-1}$), WS = Wind Speed ($\text{m}\cdot\text{sec}^{-1}$), WD = Wind Direction (degrees), TEMP = Temperature (centigrade).

Table 4. Results of paired *t*-test.

Variables	CRT	FT	AS	WS	WD	TEMP
Mean difference (N)	.0010	.0037	.481	-.0039	3.5000	.800
Standard deviation	.0070	.0039	.615	.0022	4.110	.833
Standard error of the mean	.0015	.0008	.137	.0004	.919	.186
Lower 95% CI of difference	-.0023	.0018	.193	-.0049	1.576	-.932
Upper 95% CI of difference	.0043	.0056	.769	-.0029	5.424	.409
<i>t</i> -value	.630	4.236	3.500	-7.987	3.808	1.190
Degrees of freedom	19	19	19	19	19	19
Two-tailed significance	.536	.000	.002	.000	.001	.000

Abbreviations: CRT = Clicker Reaction Time (msec), FT = Flying Time (sec), AS = Average Speed ($\text{km}\cdot\text{h}^{-1}$), WS = Wind Speed ($\text{m}\cdot\text{sec}^{-1}$), WD = Wind Direction (degrees), TEMP = Temperature (centigrade), CI = Confidence Interval.

Reliability results of archery chronometer

All data appeared to be normally distributed. The information on six data pairs is given in Table 3. There was a significant difference between two sessions of FT, AS, WS, WD, and TEMP, but no significant difference between two sessions of CRT. The results of the paired *t*-test are listed in Table 4.

The reliability of CRT measurer was ICC_(3,1) .985 with a 95% confidence interval of .962 - .994. The reliability of FT measurer was ICC_(3,1) .992 with a 95% confidence interval of .980 - .996. The reliability of AS measurer was ICC_(3,1) .990 with a 95% confidence interval of .976 - .996. The reliability of WS measurer was ICC_(3,1) 1.000 with a 95% confidence interval of 1.000 - 1.000. The reliability of WD measurer was ICC_(3,1) .742 with a 95% confidence interval of .456 - 0.889. The reliability of TEMP measurer was ICC_(3,1) .938 with a 95% confidence interval of .850 - 0.975.

Figures 7-12 show how the individual measurements vary from the mean for each measurement method of archery chronometer. Differences against mean plots were used regarding

the reliability of all measurements. The reliability again appears to be sufficient as all the data points were inside ± 1.96 standard deviation of the mean of the two measurements (Figure 7 - 12).

DISCUSSION

Validity evidence of CRT measurer in measuring the response to clicker's fall showed that the time interval, which is named as CRT, could be used as a predictor of RT in archery. CRT, which is longer than RT, includes both RT (pre-motor and motor times) and the beginning stages of Movement Time (MT). When a total response in reaction to any stimulus is considered, CRT almost equals to the response time according to the definition of RT paradigm (Figure 5). Since the clicker's fall is accepted as an auditory stimulus in archery, the time interval that is measured by the newly developed device consists of an active contraction of the muscle extensor digitorum and a gradual relaxation of the muscle flexor digitorum superficialis (Ertan et al., 2003).

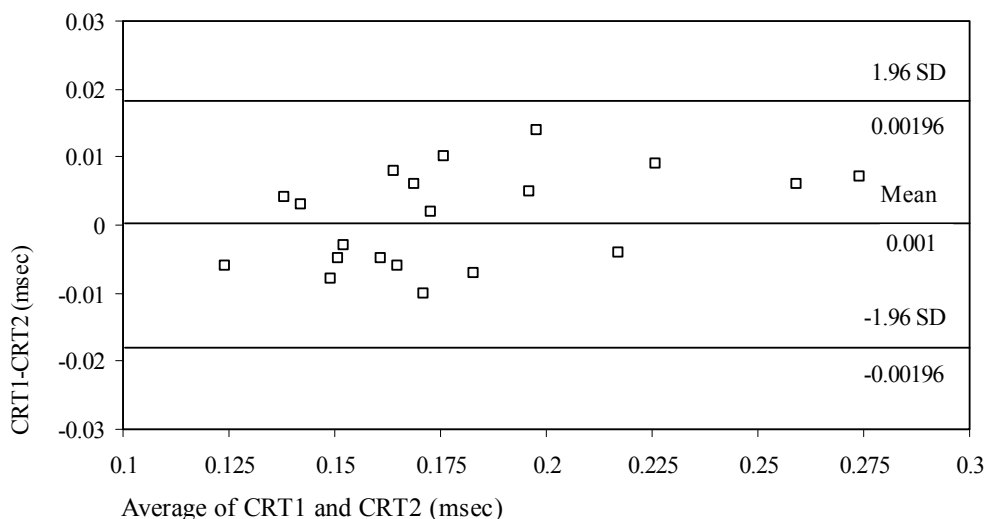


Figure 7. Bland and Altman Plot. CRT1 = results of first session of the CRT measurement versus CRT2 = results of second session of the CRT measurement.

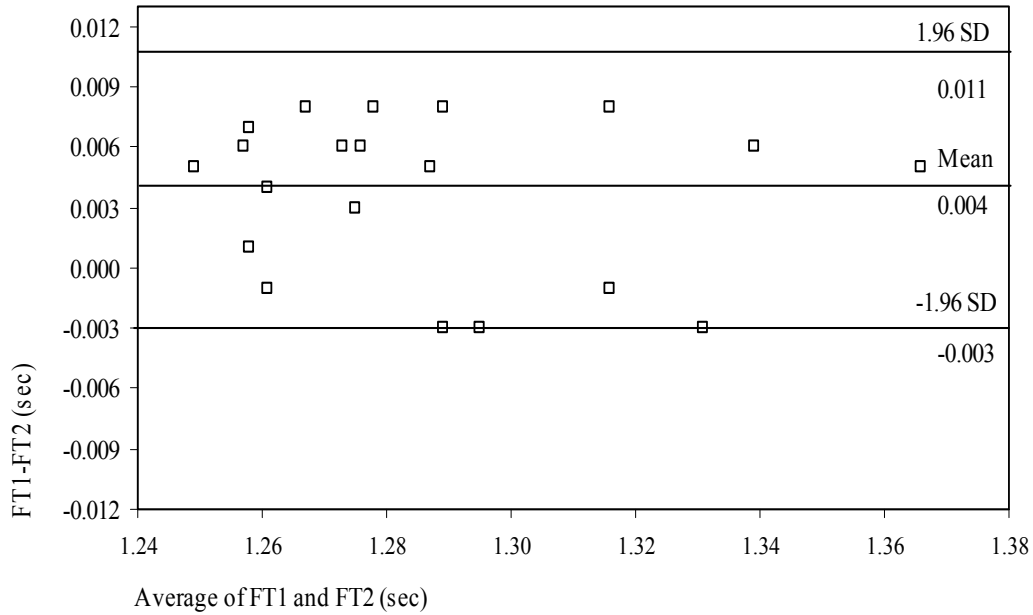


Figure 8. Bland and Altman Plot. FT1 = results of first session of the FT measurement versus FT2 = results of second session of the FT measurement.

There is also sufficient evidence to claim that Archery Chronometer is able to make reliable measurements of CRT, FT, AS, TEMP, WS and WD. It can measure any differentiation in CRT, AS, and FT and facilitate to relate these three parameters to WS, WD, and TEMP, since drawing weight of the bow and the weight, length, insertion, and feathers of an arrow is always constant for an archer. Therefore, Archery Chronometer can be used for evaluating the archers' shooting technique and the bow-arrow interaction.

When we consider CRT measurement, an archer releases the bowstring by opening three-finger

hook of the drawing hand and the point of the arrow covers 1.5 cm distance. During the CRT measurement, the arrow is in interaction with the bow and the archer. The response time of an archer to the clicker's fall is a unique method to have an idea about the archer's shooting technique by correlating CRT with the scores on the target. The link between CRT and the score on the target can be observed. Moreover, possible effects of CRT on scores can be evaluated. Thus, the interaction between an arrow and archer-bow subsystem (Pekalski, 1990) can be analyzed in this way.

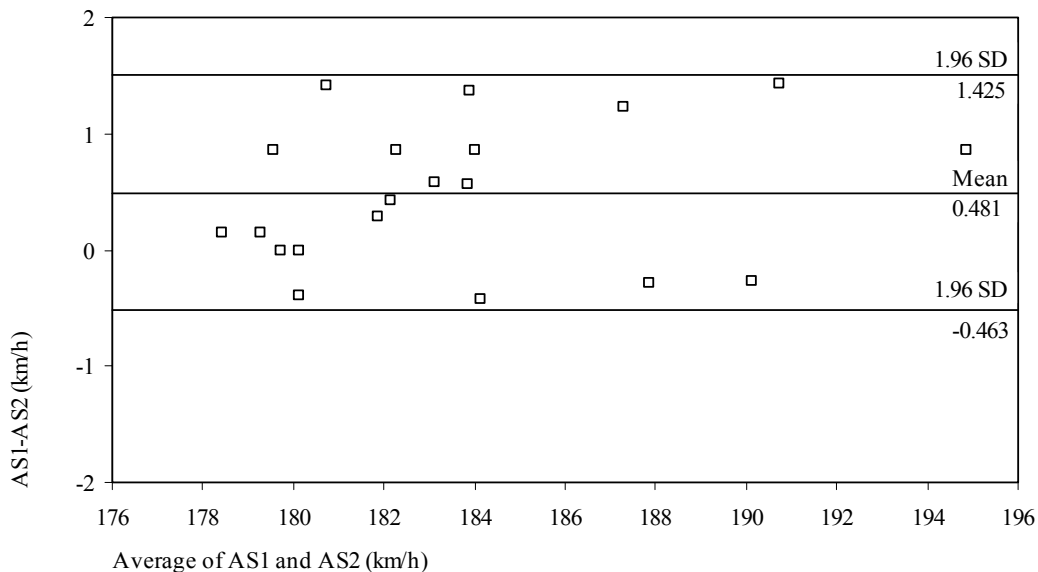


Figure 9. Bland and Altman Plot. AS1 = results of first session of the AS measurement versus AS2 = results of second session of the AS measurement.

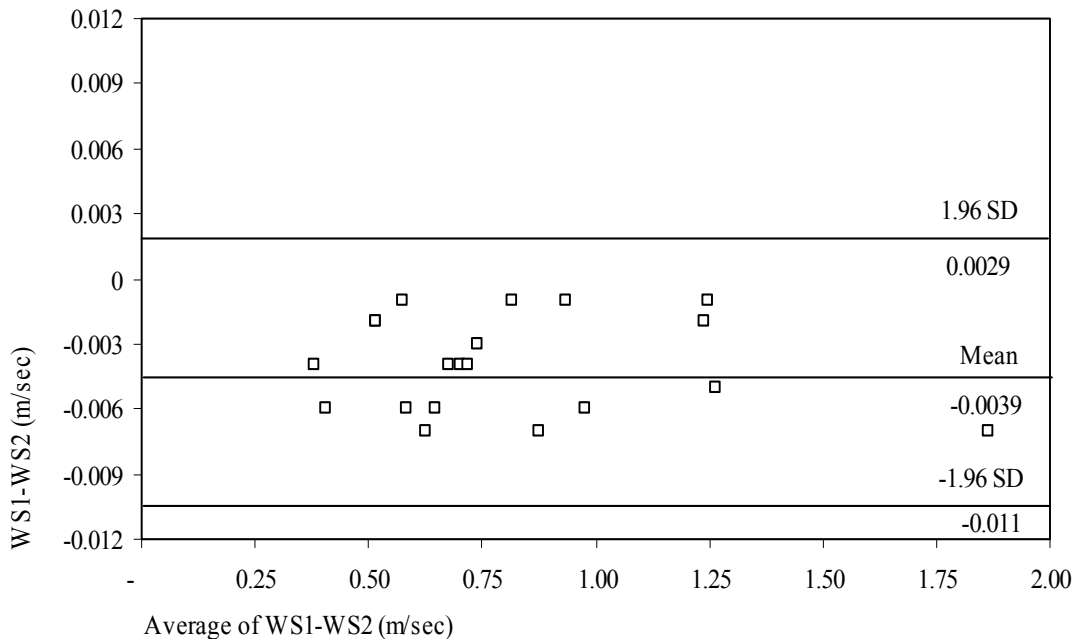


Figure 10. Bland and Altman Plot. WS1 = results of first session of the WS measurement versus WS2 = results of second session of the WS measurement.

FT/AS measurement immediately follows the CRT measurement. Archery Chronometer can also be used as an indicator for ballistic flight of an arrow. The phase 1, which defines the arrow-bow-archer interaction, affects the phase 2 or in other words the ballistic flight. Evaluation of FT/AS of an arrow facilitates to analyze both the ballistic flight itself and release technique of an archer. Ballistic flight may also be affected by the wind. The speed and the direction of the wind may alter the flying speed of an arrow. One of the advantages of the

developed device is that the researcher can gather data on the effect of wind.

CONCLUSIONS

It is concluded that the Archery Chronometer is valid in terms of predicting RT and reliable in measuring CRT, FT, AS, TEMP, WS and WD. Thus, Archery Chronometer can be used by the coaches and the archers to evaluate and enhance shooting technique in the natural settings of their training environment.

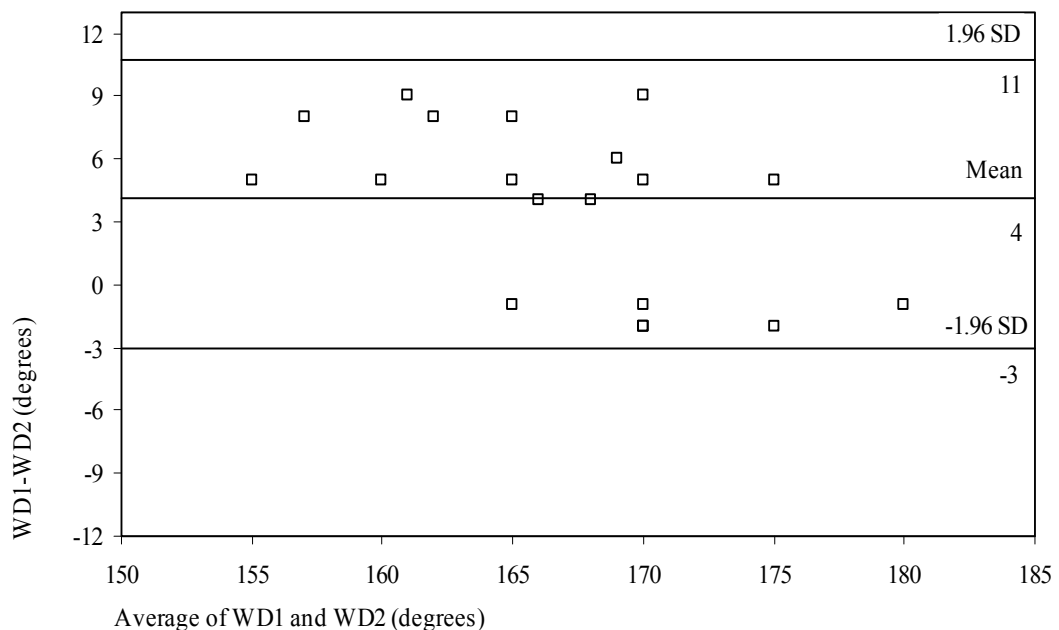


Figure 11. Bland and Altman Plot. WD1 = results of first session of the WD measurement versus WD2 = results of second session of the WD measurement.

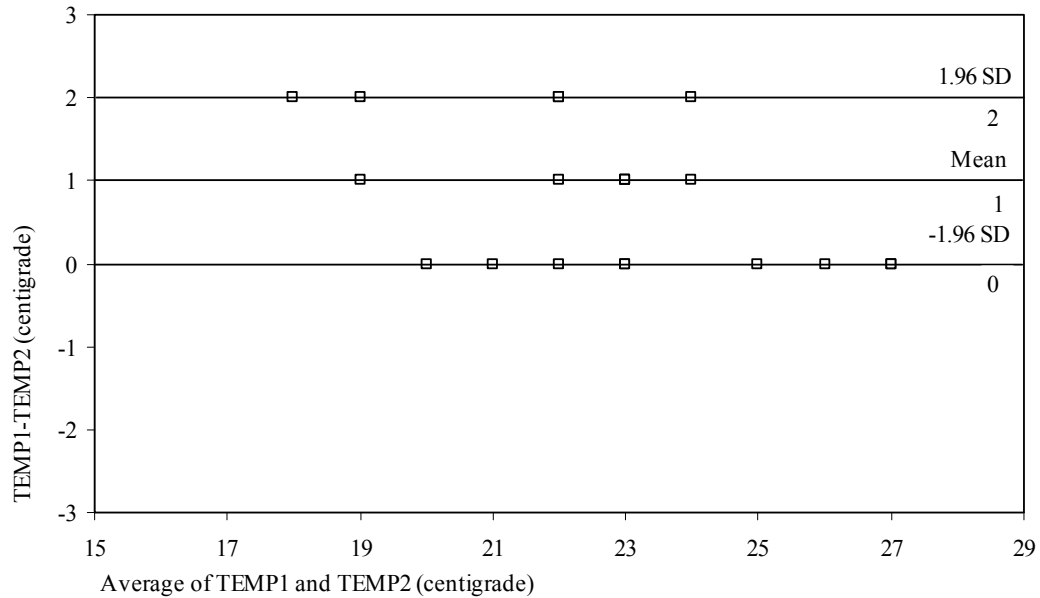


Figure 12. Bland and Altman Plot. TEMP1 = results of first session of the TEMP measurement versus TEMP2 = results of second session of the TEMP measurement.

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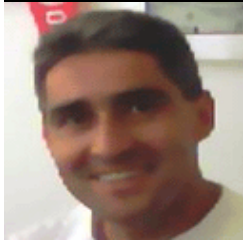
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KEY POINTS

- Clicker Reaction Time could be used as a predictor of Reaction Time in archery.
- Archery Chronometer can be used for evaluating the archers' shooting technique and the bow-arrow interaction.
- Archery Chronometer can also be used as an indicator for ballistic flight of an arrow.
- Archery Chronometer can be used by the coaches and the archers to evaluate and enhance shooting technique in the natural settings of their training environment.

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