The Marksman's motor control

I) Stabilometric study of the changes during training

Le contrôle moteur du tireur d'élite

I) Étude stabilométrique de ses changements au cours de l'entraînement

Titre court: The marksman's motor control

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Summary

The known studies of the postural control of rifle shooters do not allow to decide whether the coaches had better focus on the postural control system of their athletes or not. Trying to answer this question, within the "Fédération Française de Tir" we have undertaken a stabilometric study of the modifications of the postural control during training. The results show that, in the course of their training, the shooters get a better control of the position of their center of gravity, by reducing the degrees of freedom of their ankle and sub-talar joints. The movements of the weapon, followed with an opto-electronic system, are increasingly correlated to the movement of the center of gravity. Therefore, the coaches had better monitor the postural control of their athletes too.

To be perfectly clear, the entire study will be presented in three parts: study of the modifications of the postural control outside shooting and during the shooting, without and with optoelectronic recordings of the line of sight associated to stabilometry.

Résumé

Les études antérieures du contrôle postural des tireurs à la carabine ne permettent pas de décider si les entraîneurs doivent ou non surveiller le contrôle postural de leurs athlètes. Pour répondre à cette question nous avons entrepris au sein de la Fédération Française de Tir une étude stabilométrique des modifications de ce contrôle au cours de l'entraînement. Les résultats montrent que les tireurs, au cours de leur entraînement, acquièrent un meilleur contrôle de la position de leur centre de gravité en réduisant les degrés de liberté de leurs articulations tibio-tarsiennes et sous-astragaliennes. De plus les mouvements de leur arme, suivis par un système optoélectronique, sont de mieux en mieux corrélés aux mouvements de leur centre de gravité. Il semble donc que les entraîneurs des carabiniers aient intérêt à surveiller aussi le contrôle postural de leurs athlètes.

Pour plus de clarté, l'ensemble de cette étude sera présentée en trois parties: étude des modifications du contrôle postural en dehors du tir, pendant le tir avec et sans enregistrement optoélectronique de la ligne de visée associée à la stabilométrie.

K.W. : Rifle shooters, postural control, Stabilometry, Accuracy, Training

Mots clés: Carabiniers, Contrôle postural, Stabilométrie, Précision, Entraînement

1 Introduction

Bernstein used to show his audience an experience modeled on shooting to help them understand that the brain is unable to manage straightaway a new motor act because too many degrees of freedom are involved in a motor command: training is needed that goes through a phase of reducing the degrees of freedom [1, 2] . Indeed, to achieve a high level of performance, marksmen need to train for about five years, that is to say some 3.000 hours. The expected accuracy of the marksman justifies this effort; in the group that we studied, the center of the target measures 0.5 millimeters in diameter, 10 meters away from the shooter; this center is viewed at an angle of 17 seconds of arc.

Therefore, Bernstein was quite right when thinking of the shooter's model in his studies on the accuracy of motor control. Yet, it is among blacksmiths, and not marksmen, he discovered "the end point control": the blacksmith's hammer always hits precisely the required place, although the movements of his body parts do not follow identical trajectories: it is the goal that is controlled, not the entire movement [3]. Arutiunian and Gurfinkel [4] confirmed that pistoliers follow the strategy of the end point control that might be so caricatured : it is enough to anticipate correctly the moment when the line of sight is about to cross the center of the target and pull the trigger at the right time... nothing else to do! ...

Subsequent studies confirmed that this strategy is also used by marksmen, even beginners, and Konttinen [5] described it as 'visuomotor', which emphasizes the role of anticipation from visual data. But most of these studies have also shown that postural control is modified by training [6-11]... So, at a more or less conscious level, the marksman does not only deal with anticipation, he also changes his postural control. However, according to some authors, the relationship between the marksman's performance and the quality of his postural control has not yet been demonstrated [12-14].

To try to dispel these contradictions, we have reviewed, off and then the during firing sessions (see companion papers), the changes in the marksman's postural control while training. All these changes contribute to improve anticipation through a better prediction of the weapon movements: reducing the degrees of freedom of their ankle and sub-talar joints to reduce and regulate the acceleration of the center of gravity (CoG), reducing the degrees of freedom between the weapon and the body at the shoulder,

In this first paper we study the changes in the marksman's postural control during his training, off shooting situations.

2 Materials and Methods

2.1 Population

Among the 130.000 members of the Fédération Française de Tir, the following ones were selected, on performance criteria only:

- 37 subjects regularly engaged in national level competitions, named the 'the Nationals' (23 males, 14 females, mean age 26.5 ± 7.5 years; average size: 1.72 ± 0.08 meters)
- 35 subjects regularly engaged in regional competitions, named the 'the Regionals', (18 males, 17 females, mean age: 29.2 years ± 8.3)
- 40 controls subjects with no connection with shooting were also recruited among posturology students (18 males, 22 females, median age: 28.8 years ± 5).

No health criterion was used to select the subjects, controls as well as shooters.

2.2 Material

2.2.1) stabilometry

The subjects were recorded on stabilometric ‘clogs’ Cyber-Sabots® that allow for positioning the subject’s feet in any position, particularly the standard position: 'feet up to 30 °, heels 2 cm' apart [15]. Each clog has 6 strain gauges (working range: 10/100 kgs, threshold: 2 g). The signal from the sensor is amplified and filtered by a low pass anti-aliasing filter of 48 dB per octave, with a cutoff frequency of 20Hz. The digitization of the signal is operated by a 16-bit ADC at a sampling rate of 40 Hz according to Shannon theorem . A specific program allows editing the coordinates of the CoPs, one under each foot and one ‘resulting’ in between; this last one is represented in a Cartesian frame with the bisector of the angle formed by the inner edges of the feet as the Oy axis, and the origin O being at the intersection of this axis with the line joining the medial malleoli [16]. The maximum permissible error of measurement is one tenth of millimeter. Other metrological characteristics of this device (see 15).

2.2.2) Recording conditions

The recordings were made in an eyes open (EO) and eyes closed (EC), condition in a closed and silent room. The visual target, a black disc, 15 mm in diameter, aligned with the sagittal axis of the platform, was set 1.60 m above the ground, on a wall 2 m away in front of the subject; on his right side, 2 m away, there was a drawn curtain, on his left side, 2 m away, there was a wall with a door. The subject's feet were in the standard position, the same standard instructions were given to all the subjects [15].

2.3 Method

2.3.1) Stabilometric signal analysis

The signal analyzes focused on the shooters’ center of gravity (CoG). The CoG positions were calculated from the CoP positions by solving the differential equation of DA Winter [17, 18]. Twelve parameters were studied:

- X, Y: X and Y mean positions of the CoG.
- X2, Y2: ANØ2X and ANØ2Y: Percentage of the CoG sway amplitude in a frequency band around 0.2 Hz, compared to the sway amplitude in the remaining postural frequencies [19].
- G: Area of a standard confidence ellipse containing 90% of the CoG sampled positions [20].
- V: Area of a standard confidence ellipse containing 90% of the CoG elementary speed vectors [20].
- Vx: vectors projected on the X-axis of the CoG elementary speed vectors.
- Vy: vectors projected on the Y-axis of the CoG elementary speed vectors.
- Vm: modules of the CoG elementary speed vectors.
- A: Area of a standard confidence ellipse containing 90% of the elementary acceleration vectors of CoG [20].
- Cm: modular time constant: Abscissa of the 0.5 crossing of the autocorrelation function of the acceleration vectors of the CoG [21].

- Cx: Time constant in X: Abscissa of the 0.5 crossing of the autocorrelation function of the projections on the X axis of the acceleration vectors of the CoG [21].
- Cy: Time constant in Y: Abscissa of the 0.5 crossing of the autocorrelation function of the projections on the Y axis of the acceleration vectors of the CoG [21].

2.3.2) Statistical Analysis

Checking the normality of distributions was performed by the Anderson-Darling test, Lilliefors, Jarque-Bera and Shapiro-Wilk accepting that only one test validates the symmetry of the distribution. When necessary, the normalization was performed by passing from real values to natural logarithms values.

2.3.2.1) Principal component analysis

The principal component analyzes were performed with one explanatory factor: training, with three modalities (Controls, Regionals, Nationals); the random variables being represented by the stabilometric data.

2.3.2.2) ANOVA

The results of the principal component analyzes were confirmed by modeling according to a one-way ANOVA with three explanatory modalities.

2.3.2.3) Linear regression

The correlation between the acceleration and the mean position of the CoG was studied by linear regressions.

3 Results

3.1 Reduction of the speed and acceleration of the CoG during training

In the first statistical approach, the principal component analysis shows that the best-correlated variables to the training factor are the speed and acceleration of the CoG, in eyes open conditions (Table 1)

	F1	F2
CoG Acceleration	0.938	0.079
CoG Speed	0.863	0.453
CoG Position	0.715	0.522
Vx	0.015	0.125
Vy	-0.109	0.284
X2	0.226	0.452
Y2	0.111	0.331
Y	0.179	-0.200
Cx	-0.266	0.751
Cy	-0.416	0.605
Cm	-0.180	0.758
X	0.101	0.075

TAB 1 — Correlation between 12 stabilometric parameters and the axes F1 and F2 of the PCA

A comparison of the means shows that it is a reduction of the speed and the acceleration of the CoG during training.

An ANOVA confirmed that the reduction of the speed and the acceleration of the CoG are explained indeed by the training factor among the Controls (C), the Regionals (R) and the Nationals (N) (Table 2).

Contrast	Difference	Standardized difference	Critical Value	Pr > Diff	Significant
C vs N	148.997	6.672	2.376	<0.0001	Yes
C vs R	93.913	4.267	2.376	0.0001	Yes
R vs N	55.084	2.421	2.376	0.045	Yes

TAB. 2 — Table summarizing the results of the ANOVA
C: the Controls: R: the Regionals N: the Nationals

3.2 Changes of the correlation between the Y-mean position and the acceleration of the CoG during training.

Among the Controls, the acceleration increases as the CoG is backward (fig. 1), among the Regionals, the acceleration of the CoG does not change when the CoG is backward (fig. 2) among the Nationals, the acceleration decreases as the CoG is backward (fig. 3).

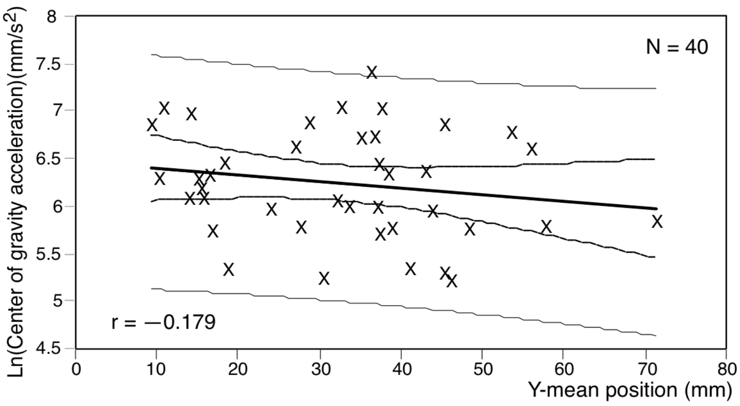

FIG. 1 — Linear regression between the position and the acceleration of the CoG, among the Controls (EO Situation).
When the CoG is more backward its acceleration increases.

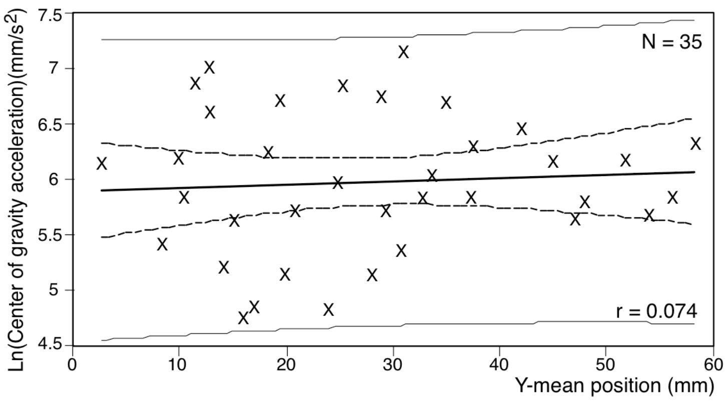

FIG. 2 — Linear regression between the position and the acceleration of the CoG, among the Regionals (EO situation)
When the CoG is more backward, its acceleration does not change.

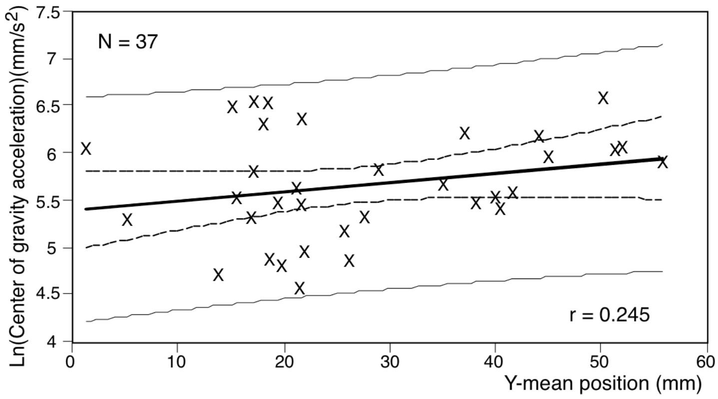

FIG. 3 — Linear regression between the position and the acceleration of the CoG, among the Nationals (EO situation).
When the CoG is more backward, its acceleration decreases.

This tactics shift between the Controls and good level shooters disappears in the EC situation.

3.3 Reduction of the time constant of the upright postural control system during training.

There is a statistically significant change of the time constant between the control subjects and trained ones, but only for the acceleration vector projections on the axes of the frame (Table 3)

		Cx	Cy	Cm
Controls (C)		0.211 ± 0.04	0.186 ± 0.029	0.148 ± 0.03
Regionals (R)		0.243 ± 0.051	0.2 ± 0.028	0.159 ± 0.031
Nationals (N)		0.232 ± 0.043	0.204 ± 0.036	0.162 ± 0.035
C/R	Student's t	3.11	2.11	1.06
	p	0.01	0.05	ns
	ddl	75		
C/N	Student's t	2.21	2.2.37	1.91
	p	0.05	0.05	ns
	ddl	73		
R/N	Student's t	0.99	0.5	0.38
	p	ns	ns	ns
	ddl	70		

TAB. 3 - Comparison of the mean of the time constant among the various levels of training (EO situation).
Cm: time constant calculated from the modulus values of the acceleration vectors of the CoG.
Cx: time constant calculated from the abscissa projection of the acceleration vectors of the CoG.
Cy: time constant calculated from the ordinates projection of the acceleration vectors of the CoG.
C: the Controls: R: the Regionals N: the Nationals

This time constant measures the system stability over time.

4 Discussion

The speed and acceleration of the CoG decrease when training. This can be seen as an improvement of the postural control, which becomes calmer, quieter, and smoother. That, a priori, can facilitate shooting accuracy.

We know that the CoG is always projected ahead of the tibiotarsal axis. A torque in rapport to that axis tends to make the subject fall forward. This torque must be cancelled by a torque, equal and opposite. Winter et al. [22] thought that the stiffness of the elastic tissue of the posterior lodges of the legs [23] was sufficient to cancel this gravitational torque. But many authors showed that this was not the case, and that a muscle contraction happened and compensated for the lack of stiffness of tendon tissue and fascia when they were relaxed [24-

27]. Thus, according to these authors, one can describe the normal postural tactics: the closer to the tibial-tarsal axis the mean position of the CoG (Y-mean posterior) is, the more necessary this muscular compensation is because the tendon and fascial tissue are then relaxed, mechanically. Therefore, to stop his fall when his body leans forward, a subject will need more or less muscular contractions when it oscillates, on average, around a more or less posterior position, i.e. whether the elastic tissues of the posterior lodges of his legs are more or less relaxed. A subject who oscillates about a very posterior mean position, whose elastic tissues are widely relaxed, will need more muscle contractions than a subject, who oscillates about an anterior position whose stiffness of his elastic tissue is already increased by the anterior position of the CoG and the dorsal flexion of the tibio-tarsal it supposes.

If one accepts that, in the stabilometric recording conditions, the acceleration of the CoG is a marker of the phasic muscle activity, then we can say that the training of the shooters is accompanied by a significant change of this normal tactics of the postural control. The Controls follow this tactics: the more posterior their CoG — Y-mean posterior — is, the more important the mean value of the acceleration of the CoG during the recording is (Fig. 1), and therefore the more important the phasic contractions of the posterior muscles of their legs are.

Among the Regionals, this tactics disappear (Fig. 2) and they are completely reversed among the Nationals, the more anterior their CoG is, the more numerous muscular contractions are on average (Fig. 3).

In fact, the acceleration of the CoG is not due solely to a phasic muscular activity, it is also related to the oscillations of the inverted pendulum and to tissue elasticity. This basic acceleration of the pendulum follows a perfectly regular and symmetrical sinusoidal function unlike the acceleration due to phasic muscle contractions whose regularity is not guaranteed .

The loss of the normal postural tactics among the Regionals (Fig. 2) shows that the acceleration of their CoG becomes more regular and symmetrical, approximate to a sine function, which improves the predictive power of the position of the CoG.

Among the Nationals the importance of muscle contractions increases when their CoG is more anterior, which is quite abnormal. Since there is no trace of phasic muscle contractions when the elastic tissues of the posterior lodges of their legs should be relaxed, i.e. when the position of their CoG is very posterior, it is reasonable to assume that a tonic contraction of the posterior muscles of their legs blocks the movements of the tibio-tarsal joints. The stabilization of the shooter would then be exclusively the work of the feet. As phasic muscle contractions occur when the CoG is forward, the opposite of the normal tactics, one can assume that the Nationals use an inverse pattern of normal subjects: when the elasticity of the foot is no longer able to stabilize the inverted pendulum during its forward movement, then a muscle contraction would occur. Which muscles would be contracted? The proper foot muscles [28, 29]? Or this muscle that is mechanically attached to them, the flexor hallucis longus [30]?

Anyway, this Nationals tactics, which bring about an economy of energy as well as a gain in speed of reaction, might explain the variation, statistically significant, of the time constant of the system.

The time constant of the upright postural system grows as the training of the shooters goes on. This increase in stability over time of the postural system facilitates the prediction of the position of the CoG as it is less subject to random accelerations.

It is surprising that the shooters' training — considerable — leads to a better prediction of the position of their CoG though the best index that can help the shooter to predict the movements of his line of sight is visual… We are therefore forced to admit that there must be some consistency between the visuomotor latencies of the athletes, very short, and the gains obtained by increasing the stability over time of the postural system.

5 Conclusion

During their training, the marksmen modify their upright postural control system. The most striking feature is the reduction and regularization of the acceleration of their CoG that facilitate the anticipation by increasing the power to predict the position of the CoG. This finding confirms that the coaches of the shooters are right to focus on the postural control of their athletes, even if the relationship between performance in shooting and perfection of the postural control appears only through a long process of premeditated observation.

We still have to study the postural control when firing, which will be the subject of companion papers.

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References

1. Bernstein N. On the construction of movements. Moscow: Medgiz; 1947.
2. Bernstein N. On dexterity and its development. In: Latash M, Turvey M, editors. Dexterity and its development. New-York: Psychology Press; 1996. p. 3-237.
3. Bernstein N. Studies of the biomechanics of the stroke by means of photo-registration. Research of the Central Institute of Labour, Moscow 1923.
4. Arutiunian G, Gurfinkel V, Mirskii M. Study on aiming at a target. Biofizika 1968; 13: 536-8.
5. Konttinen N, Lyytinen H, Viitasalo J. Rifle-balancing in precision shooting : behavioral aspects and psychophysiological implication. Scand J Med Sci Sports 1998; 8: 78-83.
6. Niinima V, Mcavoy T. Influence of exercise on body sway in standing rifle shooting. Can J Appli Sports Sci 1983; 8: 31-3.
7. Aalto H, Pyykø I, Ilmarinier R, Kahkonen H, Starck J. Postural stability in shooters. Oto-Rhino-Laryngology 1990; 52: 232-8.
8. Era P, Konttinen N, Mehto P, Saarelas P, Lyytinen H. Postural stability and skilled performance — A study on top level and naïve rifle shooters. J Biomech 1996; 29: 301-6.
9. Goodman S, Haufler A, Shim J, Hatfield B. Regular and random components in aiming-point trajectory during rifle aiming and shooting. J Mot Behav 2009; 41: 367-82.
10. Konttinen N, Lyytinen H, Era P. Brain slow potentials and postural sway behavior during sharpshooting performance. J Mot Behav 1999; 31: 11-20.
11. Konttinen N, Landers D, Lyytinen H. Aiming routines and their electrocortical concomitants among competitve rifle shooters. Scand J Med Sci Sports 2000; 10: 169-77.
12. Viitasalo J, Era P, Konttinen N, Mononen H, Mononen K, Norvapalo K, et al. [The posture steadiness of running target shooters of different skill levels.]. Kineziologjia 1999; 31: 17-27.
13. Ball K, Best R, Wrigley T. Body sway, aim point fluctuation and performance in rifle shooters : inter- and intra-individual analysis. J Sports Sciences 2003; 21: 559-66.
14. Zanevsky I, Korostylova Y, Mykhaylov V. Specificity of shooting training with the optoelectronic target. Acta Bioeng Biomech 2009; 11: 63-70.
15. A.F.P. Normes 85. Paris: ADAP (Association pour le Développement et l'Application de la posturologie) 20, rue du rendez-vous 75012 Paris; 1985. 249 p.
16. Ouaknine M. Les sabots et cyber-sabots : la conception du statodynamique. In: Podologie 2007, Entretiens de Bichat. Paris: Expansion scientifique; 2007. p. 30-7.

17. Winter D. A.B.C. of Balance during Standing and Walking. Waterloo: Watereloo Biomechanics; 1995.
18. Gagey B, Ouaknine M, Bourdeaux O, Vuillerme N, Gagey P. Why use the Center of Gravity in clinical stabilometry? Med Biol Eng Comput 2012; Submitted.
19. Gagey P, Toupet M. L'amplitude des oscillations posturales dans la bande de fréquence 0,2 Hertz: Étude chez le sujet normal. In: Lacour M, editor. Posture et Équilibre. Marseille: Solal; 1998. p. 155-66.
20. Takagi A, Fujimura E, Suehiro S. A new method of statokinesigram area measurement. Application of a statistically calculated ellipse. In: Igarashi M, Black F, editors. Vestibular and visual control of posture and locomotor equilibrium. Basel: Karger; 1985. p. 74-9.
21. Ouaknine M, Boutines C, Gagey B, Gagey P. Étude de la constante de temps du système postural d'aplomb chez le sujet âgé. In: Lacour M, Hamaoui A, editors. Posture et Équilibre; 2011. p. Sous presse.
22. Winter D, Patla A, Rietdyk S, Ishac M. Ankle muscle stiffness in the control of balance during quiet standing. J Neurophysiol 2001; 85: 2630-3.
23. Fitzpatrick R, J T, D M. Ankle stiffness of standing humans in response to imperceptible perturbation: reflex and task-dependent components. J Physiol 1992; 454: 533-47.
24. Morasso P, M S. Can muscle stiffness alone stabilize upright standing? J Neurophysiol 1999; 82: 1622-6.
25. Loram I, Maganaris C, Lakie M. Paradoxical Muscle Movement in human standing. J Physiol 2004: 556:683.
26. Casadio M, P M, V S. Direct measurement of ankle stiffness during quiet standing: implications for control modelling and clinical application. Gait Posture 2005; 21: 410-24.
27. Tauzia Ad, Ferrus T, Villeneuve P, Weber B, Gagey P. Étude stabilométrique de l'effet de la hauteur des talons sur le contrôle postural chez la danseuse professionnelle. In: Weber B, Villeneuve P, editors. Posturologie clinique Tonus, posture et attitudes. Paris: Masson-Elsevier; 2010. p. 166-72.
28. Schieppati M, Hugon M, Grasso M, Nardone A, Galante M. The limits of equilibrium in young and elderly normal subjects and in parkinsonians. Electroencephalogr Clin Neurophysiol 1994; 93: 286-98.
29. Tortolero X, Masani K, Maluly C, Popovic M. Body Movement induced by Electrical Stimulation of Toe Muscles During Standing. Artificial Organs 2007; 32: 5–12.
30. Tanaka T, Hashimoto N, Nakata M, Ito T, Ino S, Ifukube T. Analysis of Toe Pressures Under the Foot While Dynamic Standing on One Foot in Healthy Subjects. J Orthop Sports Phys Ther 1996; 23: 188-93.