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ANALYSIS OF EYE AND HEAD TRACKING MOVEMENTS DURING SHOOTING FROM THE PRONE POSITION IN BIATHLETES COMPARED TO NOVICES

A.P. KRUCHININA[a], I.S. POLIKANOVA[b]

[a] *Lomonosov Moscow State University, Leninskie Gory 1, Moscow, 119991, Russian Federation*
[b] *Federal Scientific Center for Psychological and Interdisciplinary Research, 9/4 Mokhovaya St., Moscow, 125009, Russian Federation*

Анализ движений глаз и головы при стрельбе из положения лежа у биатлонистов в сравнении с новичками

А.П. Кручинина[a], И.С. Поликанова[b]

[a] *ФГБОУ ВО «Московский государственный университет имени М. В. Ломоносова», 119991, Россия, Москва, Ленинские горы, д. 1*
[b] *ФГБУ «Федеральный научный центр психологических и междисциплинарных исследований», 125009, Россия, Москва, ул. Моховая, д. 9, стр. 4*

Abstract

Biathlon shooting is one of the most crucial aspects that determines an athlete's success. Several factors can affect shooting performance. This research was aimed at studying a range of eye and head movement parameters in biathletes of different skill levels as well as in

Резюме

Стрельба в биатлоне является одним из наиболее важных аспектов, определяющих успех спортсмена. На результативность стрельбы могут влиять различные факторы. Целью данного исследования было изучение ряда параметров движения глаз и головы у биатлонистов разного уровня подготовки, а также у новичков,

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Работа выполнена при финансовой поддержке проекта Российской Федерацией в лице Минобрнауки России (соглашение № 075-15-2024-526) «Разработка научных основ эффективных технологий с включением инновационных модулей комплексной медико-психологической и междисциплинарной реабилитации, абилитации, ресоциализации и реадаптации ветеранов и участников боевых действий, членов их семей и других затронутых категорий населения».

novices in order to identify the most relevant and differentiating ones that separate novices from professionals. Eye and head movement parameters were recorded with a Pupil Labs Invisible (PI) infrared video recording eye tracker. Recorded frequency is up 200 Hz, additive error in location determination is up to 5 deg, according the documentation. The study revealed significant differences in visual motor control parameters between elite biathletes, sub elite biathletes (with Candidate Master of Sports levels of proficiency) and novices. Elite biathletes show: a minimal gaze path length after shooting, indicating strong fixation on the target, which enhances accuracy; lower pre shooting head and gaze velocities and a reduced movement range, demonstrating strong gaze stabilization; a significantly smaller normalized ellipse square, indicating focused concentration with minimal excessive movements; and longer (twice as long as novices) and fewer fixations, with a high QIVT ratio (0.93 vs. 0.51 for novices), reflecting efficient attention allocation. Professionals blink less, correlating with improved concentration and reduced cognitive load during critical tasks, alongside shorter shooting durations. The data obtained can be used to design personalized training programs aimed at enhancing gaze stability and reducing cognitive load.

Keywords: biathlon, shooting, eye movements, gaze analysis, eye tracking.

Anna P. Kruchinina — Teaching Assistant, Department of Applied Mechanics and Control of the Faculty of Mechanics and Mathematics, Lomonosov Moscow State University, PhD in Physics and Mathematics.
Research Area: biomechanics, optimal eye tracking problems, oculography processing methods, mathematical modeling.
E-mail: anna.kruchinina@math.msu.ru

чтобы выявить наиболее значимые и отличающие новичков от профессионалов. Параметры движения глаз и головы регистрировались с помощью инфракрасного видеорегистратора Pupil Labs Invisible (PI). Частота записи — до 200 Гц, аддитивная погрешность определения местоположения — до 5 градусов, согласно документации. Исследование выявило значительные различия в параметрах зрительно-моторного контроля между элитными биатлонистами, биатлонистами субэлиты (кандидаты в мастера спорта) и новичками. Элитные биатлонисты демонстрируют: минимальную длину траектории взгляда после стрельбы, что указывает на сильную фиксацию на мишени, повышающую точность; более низкие скорости движения головы и взгляда перед стрельбой и уменьшенный диапазон движений, что свидетельствует о сильной стабилизации взгляда; значительно меньший нормализованный квадрат эллипса, что указывает на сосредоточенную концентрацию с минимальными избыточными движениями; более длительные (в два раза дольше, чем у новичков) и меньшие фиксации, с высоким коэффициентом QIVT (0.93 против 0.51 у новичков), что отражает эффективное распределение внимания. Профессионалы меньше моргают, что коррелирует с улучшением концентрации и снижением когнитивной нагрузки во время выполнения критических задач, а также с меньшей продолжительностью съемки. Полученные данные могут быть использованы для разработки персонализированных тренировочных программ, направленных на повышение стабильности взгляда и снижение когнитивной нагрузки.

Ключевые слова: биатлон, стрельба, движения глаз, анализ взора, айтрекинг.

Кручинина Анна Павловна — ассистент, кафедра прикладной механики и управления, механико-математический факультет, Московский государственный университет имени М.В. Ломоносова, кандидат физико-математических наук.
Сфера научных интересов: биомеханика, оптимальные задачи отслеживания глаз, методы обработки окулографии, математическое моделирование.
Контакты: anna.kruchinina@math.msu.ru

Irina S. Polikanova — Head of the Laboratory for Convergent Research of Cognitive Processes, Federal Scientific Center for Psychological and Interdisciplinary Research, PhD in Psychology.
Research Area: virtual reality, neuroscience, psychophysiology, cognitive science, psychophysiology and sport psychology, brain mechanisms of movement, genetic correlates of fatigue, EEG rhythms.
E-mail: irinapolikanova@mail.ru

Поликанова Ирина Сергеевна — заведующая лабораторией, лаборатория конвергентных исследований когнитивных процессов, Федеральный научный центр психологических и междисциплинарных исследований, кандидат психологических наук.
Сфера научных интересов: виртуальная реальность, нейронаука, психофизиология, когнитивная наука, психофизиология и психология спорта, мозговые механизмы движений, генетические корреляты утомления, ритмы ЭЭГ.
Контакты: irinapolikanova@mail.ru

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Biathlon shooting is one of the most crucial aspects that determines an athlete's success. Shooting is performed from both standing and prone positions. In adaptive biathlon, however, only prone shooting is allowed (Gasanov et al., 2025).

Several factors can affect shooting performance, including muzzle blast and rifle recoil, aiming patterns, stability of the body-rifle system, sight transfer strategies between targets, barrel rotation, trigger pull, muscle tremor, environment factors (temperature, pressure, wind), competition importance, and more.

The study of the eye movement strategies during aiming is an important focus area in the research of efficient shooting strategies in different sports, including biathlon.

Literature proposes two types of aiming methods:

1. Fixing the gaze on the target and bringing the "weapon" to the direction of the gaze (Goonetilleke et al., 2009). Abrams et al. (1990) refer to this type as the position-only hypothesis.

2. Focusing on the weapon and visually assisting its positioning as suggested by Rouquier and Prouzet in 1978 (Goonetilleke et al., 2009). This was called the movement-only hypothesis by Abrams et al. (1990).

Due to these differences, Ripoll et al. (1985) found that there is approximately a 0.5 s difference in the final adjustment of gaze onto the target. They explained the difference in time as that needed to attain equilibrium because the head and neck movements affect body posture and movement (Manzoni et al., 1979). The study of Goonetilleke (Goonetilleke et al., 2009) shows that approximately 2 s of aiming is a sufficient time for expert shooters. The authors also demonstrated that differences at various skill levels were related to postural balance and stability rather than aiming or any cognitive task component (Ibid.).

Gaze transfers towards the target object, as well as fixation on it, are often reported to be associated with attention processes, and specifically with the Quiet Eye (QE) phenomenon (Vickers, 2009; Ganicheva et al., 2024). QE was first studied during a throwing task in basketball (Vickers, 1996). QE represents the final fixation during aiming, made prior to hitting the target – before shooting in biathlon. As defined by Lebeau et al., 2016, Quiet Eye is a fixation where gaze movements are localized on a region or object within a 3° viewing angle for minimum 100 ms.

For instance, a series of studies investigating the gaze strategies of expert and novice shotgun shooters (Causer et al., 2010; Causer et al., 2011) revealed that expert shooters were quicker to identify the target and tracked it for a longer period (QE duration) compared to less experienced shooters. Successful shots exhibited similar characteristics across both skill levels when contrasted with unsuccessful attempts, indicating that this gaze strategy is the most effective.

Similar results have been observed in other interceptive sports tasks, such as goaltending in ice hockey (Panchuk & Vickers, 2006; Polikanova et al., 2024; Yakushina et al., 2024), returning serves in table tennis (Rodrigues et al., 2002), receiving serves in volleyball (Vickers & Adolphe, 1997); dribbling in soccer (Grushko et al., 2015).

Therefore, we can define QE as a state that has the following features:

- a critical measure of an individual's ability to maintain visual focus and concentration, particularly in high-pressure situations;
- QE is defined as the final fixation or tracking gaze directed at a specific location or object within a visual angle of 3° or less for a minimum duration of 100 milliseconds;
- the onset of QE occurs prior to the critical final phase of a movement, while its offset is marked by the gaze deviating from the target location or object by more than 3° for over 100 milliseconds (Vickers, 1996; Vickers & Williams, 2007);
- a longer duration of QE can reliably differentiate elite performers from non-elite ones, as well as successful outcomes from unsuccessful motor performances.

According to Vickers and Williams (2007), the QE duration is defined as the final fixation before firing the rifle, measured from the initial fixation until the shot. If the athlete briefly loses focus due to blinks or gun motion, a re-fixation is necessary. The final action is identified as the peak trigger force leading to the shot. Fixation duration refers to the stable interval without interruptions from blinks, head movements, or eye movements, which were manually identified and annotated.

Gaze transfer by an athlete, particularly in shooting, may not necessarily serve as an indicator of attention: athletes can switch attention, keeping fixation at the same location (Vickers, 2009). Some researchers agree that gaze location can be separated from the attention location (Posner, 1980; Posner & Raichle, 1994; Mironets et al., 2024; Shelepin et al., 2024). At the same time, a gaze shift always precedes a shift of attention to a new fixation location. Part of the cause for this correlation is that the neural structures governing saccadic eye movements and shifts in attention significantly overlap (Corbetta, 1998).

However, in some cases eye movements provide a good insight into athletes' competencies and allow distinguishing them by experience and skill. Modern eye tracking has its advantages, such as sufficient experimental validity, feasibility of use out of laboratory (in field conditions), in training, as well as the possibility to both detect changes in reactions and train the athlete to enhance the overall performance (Grushko et al., 2015).

Biathlon is considered to be a sport where aiming is essential. While eye and head movements play a pivotal role in this sport, systematic academic research in this area is not available and is represented by sporadic works (Hansen et al., 2019; Heinrich et al., 2021; Sattlecker et al., 2017; Vickers & Williams, 2007). At the same time, part of the findings are ambiguous and require further research.

This work was aimed at studying a range of eye and head movement parameters in biathletes of different skill levels as well as in novices in order to identify the most relevant and differentiating ones that separate novices from professionals.

Methods

Sample and Research Procedure

Five subjects (average age = 28, SD = 7) participated in the pilot study: masters of sports of international class (2 persons), candidate master of sports (1 person), novices (2 persons). The study involved adaptive biathlon athletes. This research was conducted during summer training camp (August 2024).

Each subject made two or three prone shootings from a 10 m distance, typical of adaptive biathlon with eye tracking (Figure 1).

Figure 1

Shooting

Note. The subject is wearing pupil invisible goggles (left), the target as recorded by a pupil invisible camera (center), an overall target view from a 10 m distance (right).

Eye and head movement parameters were recorded with a Pupil Labs Invisible (PI) infrared video-recording eye tracker (Tonsen et al., 2020; Panfilova et al., 2024). Recorded frequency was up 200 Hz, additive error in location determination was up to 5 deg, according the documentation.

All subjects volunteered for the study following a pre-signed consent and prior approval from the Ethics Committee of the Russian Psychological Society (March 2024) in line with the Declaration of Helsinki.

Data Analysis

All shots attributed to one of the three following groups were analyzed:

- elite biathletes (2 subjects, 5 shooting sequences, 27 shots in total);
- candidate master of sports (1 subject, 3 shooting sequences, 9 shots in total)
- novices (2 subjects, 5 shooting sequences, 20 shots in total).

Benchmarking was performed using Jamovi 2.4.1. Since the sample size was limited, we accepted that the data was not normally distributed and therefore decided to use the non-parametric Kruskal—Wallis criterion ($\alpha = 0.05$) to compare the shooting parameters in three test groups (elite biathletes, candidate master of sports in biathlon, novices).

Investigated Characteristics

To analyze the shooting, in this study we will exclusively focus on macroparameters. We will review sequences of shots, 5 to 8 shots to cover the target. For the sequence, we selected the parameters of time intervals between shots and their standard deviation (std). Pupil invisible provides their own fixations and gaze transfer markup; however, it is rather approximate and does not allow the assessment of the fixation parameters; therefore we made our own fixation markup.

Head and gaze movement parameters are analyzed for each shot at intervals of 1 s before and 0.3 s after shooting. Shots are marked based on the video data.

Raw data from pupil invisible (head angular velocity components, gaze position in relation to scene-camera) and calculated data (head rotation angle, eye angular velocity, gaze transfer velocity, head angular velocity and linear acceleration vector moduli) were considered. All data was processed using Python (libraries: Pandas, NumPy, and SciPy). Here, the gaze is defined as an eye's position (the optic axis direction) relative to ambient (stationary) environment; eye angular velocity refers to the rotational velocity of an eyeball relative to the head.

The following parameters were considered (Bleer et al., 2016):

1) Mean parameter and its mean root square deviation (std) are considered for head motion, while for the module, these are vertical (right/left rotation) and horizontal components of angular velocity (forward/backward rotation); vertical and horizontal components of linear acceleration. Based on the task, this set of parameters is also related to the rifle movements;

2) In terms of gaze, we analyzed mean and std of absolute value, vertical and horizontal component of angular velocity; gaze direction projections in sagittal and

horizontal planes; normalized on process latency path length (a sum of increments on all time steps).

3) In terms of the head-related eye movements, we considered a gaze-covered normalized ellipse square. All parameters related to the gaze viewpoint position on scene-camera are linked to the hardware resolution used and require normalization for further comparison. As the aiming task is tied to the target located at a fixed distance of 10 m, then the target size norming on the scene-camera frame seems reasonable. Since the task was static, the target size in the frame is fixed (27 × 13 px with camera resolution of 1080 × 1800 px).

Results

Shooting Sequence Analysis

The parameters of shot sequences and those of individual shots were compared.

We excluded gaze movement parameters from consideration in relation to the sequences as sequence duration was highly diverse between subjects. The most reliable observation parameter was the number of blinks, and a correlated number of blinks per second (Table 1). Blinking regularly with no saccadic movements significantly improves the visual information quality, yet when blinking, the athlete may momentarily lose focus on the target (Hansen et al., 2019).

To analyze the gaze properties, several aspects were considered: 1) technical: at 200 Hz data frequency, the estimation error of the maximal eye velocity is up to 10

Table 1

Mean Values of Gaze Parameters in Three Groups, Averaged over Shot Sequences (5–8 Shots per Sequence)

Parameter	Group	Mean	SD	χ^2	*p*	Effect size	DSCF pairwise comparisons	
Sequence duration (s) (time for 1 shot, s)	1 2 3	21.1 (4) 26.5 (6) 53.8 (10)	4.2 (0.6) 1.6 (1) 25.9 (3)	7.45	**.024***	0.65	1 vs 2 **1 vs 3** 2 vs 3	.268 **.038** .347
blinks per sequence	1 2 3	4.40 9.50 23.00	2.07 0.71 21.48	8.04	**.018***	0.80	1 vs 2 **1 vs 3** 2 vs 3	.119 **.036** .469
blinks per second (units/s)	1 2 3	0.20 0.36 0.38	0.06 0.04 0.12	6.54	**.038***	0.55	1 vs 2 1 vs 3 2 vs 3	.129 .070 1.000
the quality index of visual tracking (QIVT)	1 2 3	0.90 0.77 0.57	0.02 0.02 0.12	8.59	**.014***	0.76	1 vs 2 **1 vs 3** 2 vs 3	.129 **.040** .153

Note. 1 — elite biathletes, 2 — candidate master of sports, 3 — novices; PI — pupil invisible;
* $p < .05$; DSCF pairwise comparisons – Dwass—Steel—Critchlow—Fligner pairwise comparisons.

deg/s for movements of an up to 10 deg amplitude; 2) preliminary analysis of the eye movements' quantitative characteristics at 100 ms intervals before and after shooting (professional athletes) showed that the maximal velocity estimation at this fixation is 20 deg/s (including measurement and PI sampling errors). We considered the number of fixations, their duration, and the quality index of visual tracking (QIVT) (Shtefanova & Yakushev, 2008): the ratio of time when the gaze velocity was below the threshold velocity to the entire observation time (shot sequences). The number and duration of fixations depict similar patterns as QIVT. Meanwhile, the QIVT difference reliability is higher as baseline parameters are highly dependent on the sequence duration. Hence, QIVT was adopted as an integrated parameter to describe the gaze fixations.

Single Shots Analysis

The full set of the above parameters was selected to analyze single shots. We exclude head angular velocity and head acceleration modulus from our consideration in view of statistical indistinction by Kruskall—Wallis criterion ($p > .05$) or insignificant effect size. Regarding the head movement parameters, we shall focus on mean vertical linear accelerations of the head (associated with muzzle vertical movements). Gaze movements describe std of position in sagittal and horizontal planes.

Table 2 and 3 show the results of a statistical comparison of shot parameters, head, and gaze movements during shooting in the three groups. The tables also display statistical results of the pairwise comparison conducted by means of the Dwass—Steel—Critchlow—Fligner criterion. Insignificant parameters are excluded.

Discussion

The results of statistical analysis for shots parameters, analyzed individually, showed significant differences between the three groups for the selected parameters (Table 1). Pairwise comparison revealed a number of relevant patterns. The "gaze path length" and "normalized ellipse square" proved to be the most distinguishing parameters. Elite biathletes demonstrate the lowest scores and low standard deviation (SD) both before and after shooting. This might be due to gaze stabilization coupled with extended fixation, which terminates as soon as the shot is made.

Other notable distinguishing parameters include: mean angular velocity and vertical component of head acceleration before the shot, mean gaze velocity, std of vertical and horizontal gaze position, and normalized ellipse square.

Gaze path length of elite biathletes after shooting is significantly shorter compared to the other groups.

Mean head velocity of elite biathletes before shooting is also marked by the lowest values, while there is an increased value for sub-elite level athletes (candidate master of sports) and novices.

Table 2

Statistical Comparison Results Head and Gaze Parameters during Shooting in Three Groups on Time Interval: From 1 s before Shoot to 0.3 s after Shoot

Parameter	Group	Mean	SD	χ^2	*p*	Effect size	DSCF pairwise comparisons	
Mean vertical linear head acceleration	1	−0.91	0.02	15.94	**< 001**	0.25	1 vs 2	.49
	2	−0.92	0.01				**1 vs 3**	**< .001**
	3	−0.92	0.02				2 vs 3	.22
Mean horizontal linear head acceleration	1	−0.31	0.03	7.39	**< .025**	0. 1	**1 vs 2**	**.03**
	2	−0.34	0.01				1 vs 3	< .09
	3	−0.34	0.03				2 vs 3	1
Std of vertical gaze movements (in sagit. planes) (deg)	1	0.6	0.8	18.34	**< .001**	0. 3	**1 vs 2**	**.01**
	2	1	1.1				**1 vs 3**	**< .001**
	3	1.1	2.3				2 vs 3	.781
Std of horizontal eye movement (transverse plane), (deg)	1	19	21.3	26.49	**< .001**	0.4	**1 vs 2**	**.011**
	2	38	21.5				**1 vs 3**	**< .001**
	3	44.9	27				2 vs 3	.801
Std of vertical gaze velocity (in sagit. planes) (deg/s)	1	6	8.9	21.5	**< .001**	0.3	**1 vs 2**	**.01**
	2	15.9	6.8				**1 vs 3**	**.006**
	3	16.5	16				2 vs 3	.656
Std of horizontal gaze velocity (transverse plane), (deg)	1	10	13	10.42	**.005**	0.15	**1 vs 2**	**.013**
	2	23	27				**1 vs 3**	**< .001**
	3	24	17.8				2 vs 3	.855
Mean value of gaze velocity module (deg/s)	1	8	15	25.5	**< .001**	0.4	1 vs 2	.132
	2	24	21				**1 vs 3**	**.002**
	3	24	17				2 vs 3	.943
Gaze path length (deg)	1	223	140	24.1	**< .001**	0.4	**1 vs 2**	**0**
	2	512	145				**1 vs 3**	**0**
	3	467	217				2 vs 3	.612
Normalized ellipse square	1	8.2	17.9	29.3	**< .001**	0.44	**1 vs 2**	**0**
	2	70.3	101.7				**1 vs 3**	**0**
	3	80.0	111.9				2 vs 3	1

Table 3

Statistical Comparison Results of Head and Eye Velocity during Shooting in Three Groups

Parameter	Group	Mean	SD	χ^2	*p*	Effect size	DSCF pairwise comparisons	
1 s before the shoot								
Mean of head horizontal angular velocity (deg/s)	1	0.22	2.0	14.25	**< .001**	0.21	**1 vs 2**	**.007**
	2	0.23	2.5				1 vs 3	.073
	3	0.19	0.8				**2 vs 3**	**.007**
Mean of vertical component head acceleration	1	−0.91	0.02	10.69	**.005**	0.154	1 vs 2	.355
	2	−0.92	0.01				**1 vs 3**	**.004**
	3	−0.93	0.02				2 vs 3	.346
Mean of absolute gaze velocity value***	1	25.2	31.8	8.29	**.016**	0.130	1 vs 2	.109
	2	37.9	21.2				**1 vs 3**	**.023**
	3	39.8	26.5				2 vs 3	.981
Gaze path length	1	269	15.8	19.78	**< .001**	0.289	**1 vs 2**	**< .001**
	2	556	15.9				**1 vs 3**	**.001**
	3	486	25.8				2 vs 3	.546
Std of horizontal gaze position	1	1	1	27.93	**< .001**	0.427	**1 vs 2**	**< .001**
	2	4.8	4.4				**1 vs 3**	**< .001**
	3	5.1	4.6				2 vs 3	. 888
Std of vertical gaze position	1	0.62	0.48	23.14	**< .001**	0.356	**1 vs 2**	**< .001**
	2	1.51	1.04				**1 vs 3**	**< .001**
	3	1.75	2.09				2 vs 3	1
Normalized ellipse square	1	4.1	5.6	30.01	**< .001**	0.460	**1 vs 2**	**< .001**
	2	69.5	93.3				**1 vs 3**	**< .001**
	3	68.5	113.0				2 vs 3	.801
0.3 s after shooting								
Mean of absolute gaze velocity value***	1	12.6	19.9	11	**< .001**	0.167	1 vs 2	.079
	2	26.4	33.4				**1 vs 3**	**< .001**
	3	27.6	24.4				2 vs 3	.260
Gaze path length	1	225	103	0.1	**< .001**	0.325	**1 vs 2**	**.012**
	2	403	227				**1 vs 3**	**< .001**
	3	485	248				2 vs 3	.104
Std of horizontal gaze position	1	0.83	0.82	22.42	**< .001**	0.344	**1 vs 2**	**< .001**
	2	2.38	1.16				**1 vs 3**	**< .001**
	3	2.46	2.25				2 vs 3	.827

Table 3 (ending)

Parameter	Group	Mean	SD	χ^2	*p*	Effect size	DSCF pairwise comparisons	
Std of vertical gaze position	1	0.70	1	16.76	.005	0.163	**1 vs 2**	**.012**
	2	0.74	0.23				**1 vs 3**	**.022**
	3	0.85	0.16				2 vs 3	.970
Normalized ellipse square	1	5.94	4.15	21.67	< .001	0.344	**1 vs 2**	**.001**
	2	12.72	8.4				**1 vs 3**	**< .001**
	3	16.15	15.6				2 vs 3	.992

Note. 1 — elite biathletes, 2 — candidate master of sports, 3 — novices; PI — pupil invisible; DSCF pairwise comparisons — Dwass—Steel—Critchlow—Fligner pairwise comparisons.

*** STD absolute value of gaze velocity is not presented, since they illustrate the same dependency.

Mean pre-shooting gaze velocity is significantly lower for elite biathletes compared to candidate masters of sports and novices, which suggests a higher aiming stability.

Std of gaze position horizontally and vertically before and after shooting for elite biathletes is featured by substantially lower values, which testifies to high stability of eye velocity of professionals. This parameter is considerably lower for elite athletes compared to the other groups.

Normalized ellipse square is also significantly lower for elite biathletes than for other subjects. This testifies to the high aiming stability.

The above patterns speak of a significantly greater eye stabilization of professionals, which is reflected in lower eye and head velocity both before and after shooting, their lower values of mean square deviations, and shorter gaze path length.

Head movement parameters show substantial differences at 1 s interval before shooting but are absent at 0.3 s interval after shooting. This can be attributed to the non-sensitivity of the chosen post-shooting interval. However, according to Heinrich (2022), it is worthwhile to perform a detailed analysis for several post-shooting interval options in the future.

Results of statistical analysis of the sequence-averaged shooting parameters allowed us to distinguish a number of parameters that set professionals apart from novices (post-hoc pairwise comparisons showed significant differences only between elite biathletes and novices) (Table 2): the number of blinks per sequence, time taken to blink, total fixation time/target coverage time (QIVT), mean head velocity before the shooting, mean eye velocity, mean value of linear acceleration, mean time between shots, and normalized ellipse square.

PI does not present data on pupil size, making it impossible to include pupil dynamics-related features, the analysis of which is also of interest when considering fixation parameters.

These findings extend the trends previously discussed in the literature (Janelle et al., 2000; Goonetilleke et al., 2009; Hansen et al., 2019; Vickers & Williams, 2007). Earlier studies show that professional athletes, and specifically shooters, have been characterized by a greater stability of postural balance, and a longer and more stable QE. Meanwhile, there are ambiguous outcomes on the duration of QE in different studies. Vickers and Williams (2007) recorded the movement of a trigger movement with an external camera and defined “QE as the final fixation that was maintained on any part of the target for more than 100 ms. before and after the trigger pull.” Biathletes demonstrated significant individual differences in the duration of final fixation before shooting via Scatt (SCATT Eletronics LLC, Moscow, Russia) shooting system (MX – 02), ranging from around 950 ms to approx. 4000 ms with 100% accuracy (Heinrich et al., 2020). Yet, in prone position, this parameter ranged from 1500–4000 ms likewise with a 100% accuracy.

In our study, QIVT (the total fixation time to target coverage time ratio) is an integrated parameter of number and duration of fixations (we believe the gaze transfers at a peak velocity of maximum 20 deg/s). QIVT shows a clear pattern: for elite biathletes, this parameter is 0.93, for candidate master of sports – 0.67, for novices – 0.51 (Table 2).

Larger mean QIVT values of elite athletes compared to both novice and candidate master of sports may signal that elite biathletes have a greater capacity for concentration and attention, which allows them to keep their attention on key elements during competition for a longer time. It may also suggest that elite athletes are better at processing visual information and taking more reasoned decisions under stress, both of which are essential to their successful performance.

Other interesting findings were also observed for blinks number on the shooting series. Elite biathletes have considerably fewer blinks in contrast to the other groups (Table 2). This pattern is kept when the number of blinks is normalized for the time of shooting sequences. This also correlated with the duration of shooting.

The results we obtained are, in general, consistent with the vast data on greater QE of professional shooters (Dahl et al., 2021; Hansen et al., 2019; Ripoll et al., 1985; Vickers & Williams, 2007).

Vickers attributes QE duration to the neural network of vigilance, which coordinates the orienting (directs attention) and executive (recognizes the reached target) networks. If QE is continuous, this suggests a good optimization of attentional resources by the vigilance network. Later studies (Vickers, 2012) examined the dorsal (DAN) and ventral (VAN) attention networks. DAN keeps focus by blocking distracting stimuli from VAN that is responsible for memory recording and emotional control. QE of extended duration acts as a mental buffer, preventing distraction from intrusive thoughts and emotions, thus enhancing concentration. Therefore, longer fixations among biathletes enable them to concentrate better and avoid distractions.

Several studies favor the “choking under monitoring pressure” model (Baumeister, 1984; Lewis & Linder, 1997; Belletier et al., 2015). According to this model, high-automated routine actions that require minimum deliberate effort are optimal for high performance, including at high workloads and under monitoring pressure. In the meantime, high-skill athletes have a strong outward focus of attention and tend to focus on key task aspects resulting in improved performance (Wulf et al., 2001; Wulf et al., 2002). When attention is centered on task aspects, it becomes the centerpiece of success without being distracted by minor tasks or concerns (Beilock & Carr, 2001; Eysenck, 1982).

Output and Conclusion

The study revealed significant differences in visual-motor control parameters between elite biathletes, sub-elite biathletes (candidate master of sports) and novices. The gaze path length after shooting became one of the key distinguishing factors, which appeared to be minimal among professionals and was also characterized by a low standard deviation. This testifies to the elite athletes' ability to maintain their gaze fixations on the target even after shooting is complete, which mitigates destabilizing movements and improves accuracy.

Basic biathlete patterns of eye and head movements during prone shooting are as follows:

1. Gaze Movements Stability. Elite biathletes demonstrate lower pre-shooting mean head and gaze velocity values, as well as a lower movements range (standard deviation) in all directions. This attests to a strong gaze stabilization during shooting.
2. Spatial Accuracy. The normalized ellipse square is considerably smaller for elite athletes, which reflects their ability to concentrate on core areas with no excessive movements.
3. Fixations number and duration (integrated QIVT parameter). Elite biathletes have longer fixations (2 times longer than novices) and a smaller number of fixations. Their total fixations time is close to the time of target coverage (0.93 vs. 0.51 for novices). That indicates efficient attention allocation.
4. Blinking. Professionals blink less, which correlates with improved concentration and reduced cognitive load during critical task moments. They also have shorter shooting duration.

The following summarizing conclusions regarding the practical application of the obtained results can thus be drawn. In addition to increasing the shooting rate, training should be aimed at developing a stabilized gaze with an emphasis on continuous gaze fixation on the target both during and after shooting, as well as on continuous gaze fixation on a single spot or transfer between spots. Furthermore, a reduction of excessive head and eye movements, blink dynamics, and QIVT along with the shooting rate can serve as technical improvement markers.

Limitations

This study contributes to the understanding of neurocognitive mechanisms of successful shooting in biathlon by expanding theoretical models of attention (Vickers, 2012) and confirming the importance of skill automatization (Baumeister, 1984). The data obtained can be used to design personalized training programs aimed at enhancing gaze stability and reducing cognitive load. At the same time, a larger sample is required to widen the study to improve on the results obtained. Although a significant number of trends has been detected in eye movements during shooting of elite biathletes compared to sub-elite ones and novices, the limited sample narrows the outcomes and requires further research.

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