



Adaptive Regulation in Precision Sport: A Multimodal Study of Cognitive, Autonomic, and Motor Integration

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Background and Objective. Self-regulation under performance demands is essential in precision sports such as shooting and archery. While previous research has examined cognitive, physiological, or motor aspects of performance separately, limited evidence exists on their integrated adaptation within an embodied performance framework. This study aimed to investigate how cognitive performance, autonomic regulation, and fine motor control adapt across a structured training period, and whether such training enhances performance stability under controlled auditory pressure as a novel environmental constraint.

Methods. Eight athletes (age: 35.2 ± 15.7 years) from precision sports participated in a longitudinal within-subject study. Assessments were conducted at baseline, after Training Block 1 (mid-assessment), and after Training Block 2 (final assessment). Multimodal measurements included Heart Rate Variability (HRV, RMSSD) for autonomic regulation, Automated Neuropsychological Assessment Metrics (ANAM) for cognitive performance, and Dexterity Performance Assessment (DPA) for fine motor control. During the final assessment, a controlled auditory pressure condition was introduced during the variable target task (DPA) to evaluate performance stability under environmental constraint.

Results. Cognitive performance measured by ANAM showed improved reaction time ($2,186.95 \pm 84$ ms; -5.30% , $p < 0.001$), while DPA results indicated reduced variability in dexterity performance (94 ± 2 ; -3.03% , $p < 0.001$). Physiologically, HRV (RMSSD) increased from 16.33 to 23.33 ms ($p < 0.05$), suggesting improved autonomic regulation across the training period. Together, these findings indicate coordinated improvements across cognitive, autonomic, and motor domains during the structured training period.

Conclusions. The results suggest that structured training may enhance integrated regulation of cognitive, autonomic, and motor systems in precision sport athletes, as reflected by faster reaction time, increased HRV, and reduced motor variability. Performance was maintained under a controlled auditory pressure condition, indicating stable task execution under environmental constraint. These findings highlight the potential utility of multimodal assessment for evaluating integrated adaptations and performance readiness in precision sports.

Keywords: Dexterity; embodied cognition; archery; shooting; high performance

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Informed Consent Statement: This study was approved by the Ethics Committee of Lithuanian Sports University (23 03 2026, No. MNL-SVA (M)-2026-872). All participants provided written informed consent prior to participation. The study was conducted in accordance with the Declaration of Helsinki.



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