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Short Report

Comparative performance of wearable ECG devices for rhythm monitoring in endurance athletes

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1. Introduction

Endurance athletes frequently present with symptoms suggestive of arrhythmias, which are often intermittent and brief [1,2]. Standard diagnostic evaluations may therefore fail to capture transient or exercise-related arrhythmias, leading to delayed or inconclusive diagnoses. Wearable technologies offer opportunities for prolonged rhythm monitoring, but important limitations remain. Photoplethysmography (PPG) is unreliable during high-intensity exercise due to susceptibility to motion artefacts, vibrations and cold skin. ECG-based wearables, while theoretically more accurate, are similarly prone to signal degradation caused by sweating and movement [3,4]. We therefore evaluated the signal quality and user experience of multiple wearable ECG devices during both a supervised cycling session and extended ambulatory monitoring in endurance athletes.

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2. Methods

2.1. Study design

This prespecified observational cohort study was embedded within a prospective, interventional crossover trial involving repeated, supervised prolonged cycling sessions (ClinicalTrials.gov ID NCT06715748). Fifteen healthy recreational cyclists aged 18–50 years were recruited via advertisements at local sports clubs. Exclusion criteria were known cardiovascular, metabolic, or respiratory disease and established cardiovascular risk factors.

2.2. Rhythm monitoring

Three wearable ECG devices were evaluated: a single-lead ECG patch (SLP; RootiRx), a non-linear multi-lead ECG patch (MLP; Byteflies), and a single-lead ECG chest strap (SLCS; Frontier X2). All three devices are CE-marked; both patch-based systems (SLP and MLP) have additionally received FDA 510(k) clearance. Of the three, only the Frontier X2 is currently commercially available.

Each device generated automated reports on recording duration, ECG interpretability, heart rate, and arrhythmic events. All recordings were subsequently reviewed manually. Interpretable ECG segments were defined as those with a stable baseline and clearly identifiable P waves, QRS complexes, and T waves.

2.3. Study protocol

Participants underwent two monitoring phases: a standardized 3-hour cycling session and sequential 7-day ambulatory monitoring during usual daily activities. The exercise protocol was individualized based on heart rate zones and functional threshold power, derived from prior lactate threshold testing, to reflect high-intensity cycling demands. For ambulatory monitoring, devices were worn sequentially for seven days each. At the end of each monitoring period, participants completed a standardized questionnaire assessing comfort, fit during exercise, sleep interference, skin irritation, and overall satisfaction.

2.4. Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics 30. Data are presented as mean ± SD or median [IQR], as appropriate. Between-device differences were assessed using repeated-measures ANOVA or Friedman tests, with Bonferroni-adjusted post-hoc comparisons. Missing data due to device detachment or participant dropout were treated as missing without imputation. A two-sided p-value <0.05 was considered statistically significant.

3. Results

3.1. Participant baseline characteristics

The study included 15 healthy recreational athletes (n = 9 men) with a mean age of 36 ± 2 years. Participants had excellent exercise capacity, with a mean VO_2max of 61.1 ± 2.69 ml/kg/min (164 ± 29% of predicted), FTP of 270 ± 11 W, and maximum heart rate of 188 ± 2 bpm. Complete datasets were available for 11 participants across both the supervised cycling session and the seven-day ambulatory monitoring period.

3.2. Direct comparison during a three-hour supervised cycling session

Total recording time and interpretable ECG recordings (**See** Fig. 1 Panel B)

Total recording time did not differ significantly between devices (SLP: 227 ± 29 min; SLCS: 203 ± 18 min; MLP: 224 ± 32 min; $p = 0.066$). However, the percentage of interpretable ECG recordings was significantly higher for the SLCS than for both the SLP and the MLP (99.87% [99.33–100.00] vs. 91.60% [60.40–100.00] vs. 77.07% [30.09–97.86]; $p = 0.009$ and $p = 0.030$, respectively).

3.3. Extended ambulatory monitoring (Fig. 1, panel B and C)

3.3.1. Sports sessions, recording duration and coverage

The number of recorded running and cycling sessions was comparable across devices (running: SLP, 2 [1–4]; SLCS, 1 [0–2]; MLP, 0 [0–1]; $p = 0.211$; cycling: SLP, 4 ± 3; SLCS, 4 ± 2; MLP, 3 ± 2; $p = 0.175$). Total recording time, which included exercise sessions and periods of daily activities of living, differed significantly between devices (SLP: 10,080 ± 0 min; MLP: 6767 ± 1861 min; SLCS: 2533 ± 1798 min; $p < 0.001$), with post-hoc comparisons confirming longer recording time for the SLP versus both the SLCS and the MLP (both $p < 0.001$), and for the MLP versus the SLCS ($p = 0.002$).

Although absolute recording time during sports did not differ significantly between devices, the SLCS captured a substantially higher proportion of its total recordings during sports than the SLP and MLP (SLCS 33 ± 27% vs SLP 5 ± 3% vs MLP 7 ± 3%; $p = 0.021$ and $p = 0.037$, respectively).

3.3.2. ECG signal interpretability

The percentage of interpretable ECG recordings differed significantly between devices (SLP: 93% [50–99], SLCS: 99% [93–100], and MLP: 79% [7–99]; $p < 0.001$). Post-hoc comparisons revealed significantly lower interpretability for the MLP relative to both the SLP and SLCS ($p = 0.008$ and $p = 0.006$, respectively).

3.3.3. User experience

Fit during sports was rated as "perfect" by 5/11 athletes (46%) for the SLCS, 3/11 (27%) for the SLP and 1/11 (9%) for the MLP. Negative fit ratings ("bad fit") were reported only for the MLP (2/11; 18%). Clinically relevant skin irritation (moderate or severe) was most common with the MLP (10/11; 91%), followed by the SLP (6/11; 55%) and least common with the SLCS (2/11; 18%). At study completion, 9/11 athletes (82%) identified the SLCS as their preferred device, while 2/11 (18%) preferred the MLP.

4. Discussion

The SLCS provided the highest proportion of interpretable recordings during exercise, whereas patch-based devices enabled longer continuous monitoring at the cost of lower interpretability during sports and a higher frequency of skin irritation. The superior exercise signal quality of the chest-strap device is likely attributable to more stable electrode–skin contact during movement and perspiration, thereby reducing motion artefact in high-intensity settings. Patch-based systems, by contrast, were more susceptible to detachment and signal degradation during exercise [3–6]. The chest-strap device was often removed after exercise and not consistently reattached, owing to residual moisture after showering and reduced comfort during daily activities and sleep.

This behaviour resulted in extended periods without rhythm monitoring, a limitation that does not arise with continuously worn devices such as ECG patches or implantable loop recorders, which provide uninterrupted surveillance [4]. Nevertheless, approximately one-third of all recordings obtained with the SLCS were captured during exercise, compared with <10% for the patch-based devices. Despite its shorter overall wear time, the SLCS maintained a median of 99% interpretable ECG recordings, underscoring its reliability for rhythm assessment during physical activity even when worn predominantly during sports.

User experience emerged as a key determinant of device adherence. Patch-based systems were generally better tolerated during daily activities and sleep, but were associated with more frequent skin irritation. Chest-strap devices were preferred during sports due to superior fit and comfort.

These findings highlight a fundamental trade-off between signal quality during exercise and long-term wearability, suggesting that a single-device approach to rhythm monitoring in athletes is suboptimal [7]. Device selection should be guided by clinical context: chest-strap ECG systems are best suited for capturing exercise-related arrhythmias, whereas patch-based devices are more appropriate for prolonged monitoring outside of exercise.

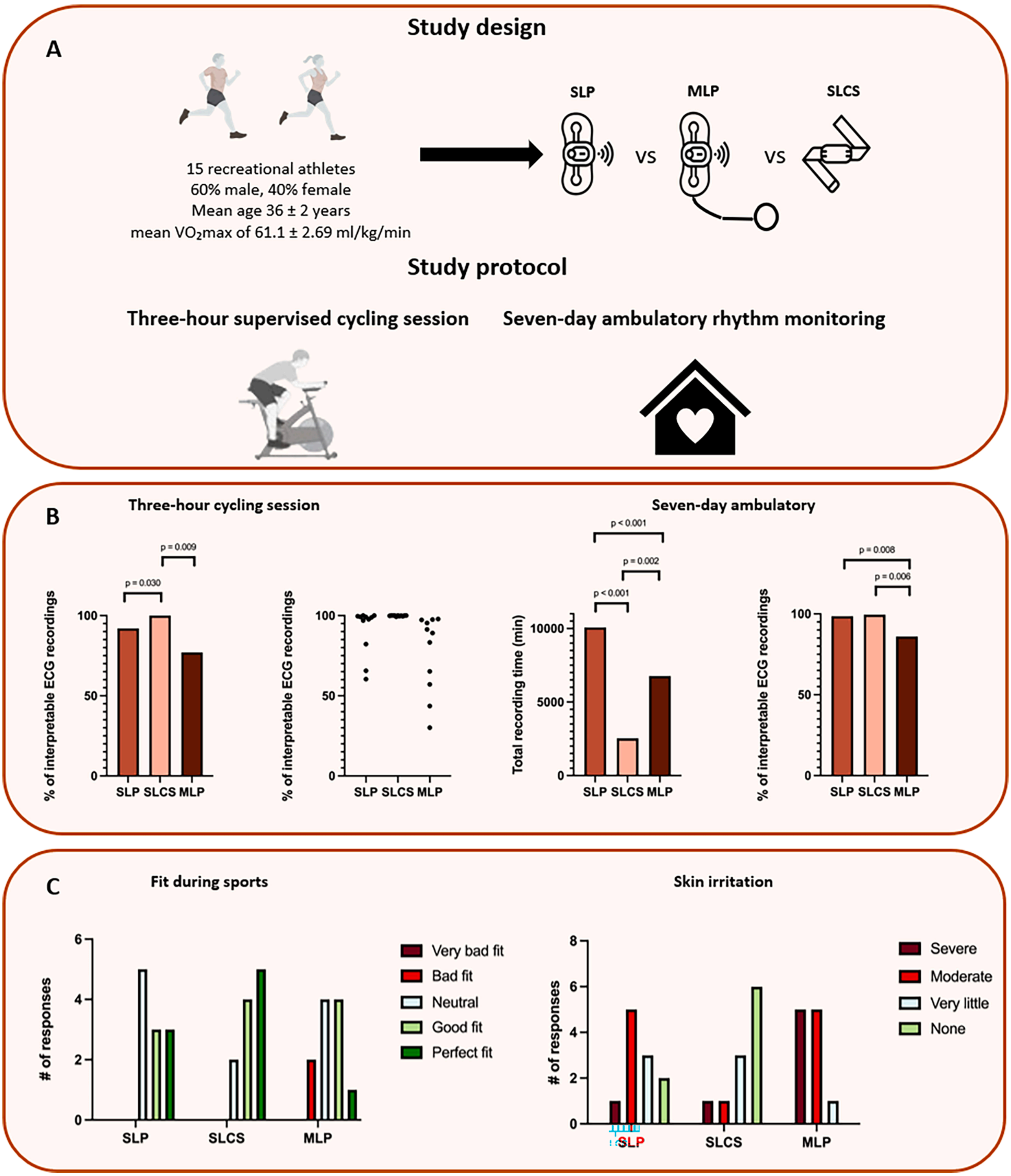

Fig. 1. Summary of study design, device performance, and user experience.
(A) Overview of the study design, including a standardized 3-hour cycling session with simultaneous device use and sequential 7-day ambulatory monitoring.
(B) Device performance. Left: percentage of interpretable ECG recordings during the 3-hour cycling session, presented as group-level bar plots with individual data points for each device in the scatter plot (SLP: single-lead patch; SLCS: single-lead chest strap; MLP: multi-lead patch). Right: ambulatory monitoring results, including total recording time (minutes) and percentage of interpretable ECG recordings per device.
(C) User experience. Questionnaire-based outcomes displayed as number of responses per category (5-point Likert scale). Left: fit during sports. Right: skin irritation. The x-axis represents device type and the y-axis the number of responses.

4.1. Limitations

This study is limited by a small sample size, a homogeneous population of recreational cyclists, low arrhythmia burden, non-randomized sequential device use, and reliance on self-reported user experience. Findings should be interpreted in the context of cycling-specific biomechanics, as motion artefact and device performance may differ across other exercise modalities, which, while present in this cohort, were underrepresented.

5. Conclusion

In endurance athletes, the SLCS demonstrated superior signal quality during exercise and was the preferred device for sports-related rhythm monitoring. Patch-based ECG systems, while more susceptible to motion artefacts and skin irritation during repeated or high-intensity exercise, offer substantially longer recording durations and greater comfort during daily activities and sleep. Wearable ECG selection should therefore be individualized according to monitoring goals: chest-strap devices appear optimal for evaluating exercise-associated symptoms and arrhythmias, whereas patch-based systems are better suited for prolonged ambulatory rhythm monitoring.

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Disclosures

None of the authors has any financial or non-financial relationships with the companies manufacturing or commercializing the three ECG devices evaluated in this study. The companies had no role in study design or manuscript preparation.

Data availability statement

The data of this manuscript is available on reasonable request.

Ethical approval

The study protocol was approved by the institutional Ethical Committee and conducted in accordance with the principles of the Declaration of Helsinki.

Author agreement

All authors had full access to the study data, verified data integrity and accuracy, contributed to manuscript drafting and critical revision, and approved the final manuscript.

CRediT authorship contribution statement

Boris Delpire: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rik Pauwels:** Writing – review & editing, Project administration, Data curation. **Benjamin Peters:** Writing – review & editing, Data curation, Conceptualization. **Jarne De Paepe:** Writing – review & editing, Data curation. **Youri Bekhuis:** Writing – review & editing. **Vincent Van Hemelen:** Writing – review & editing, Data curation. **Jean-Baudouin Van Leeuw:** Writing – review & editing. **Johanna Lammens:** Writing – review & editing. **Olivier Ghekiere:** Writing – review & editing, Conceptualization. **Marius Myrstad:** Writing – review & editing. **Andre La Gerche:** Writing – review & editing. **Hielko Miljoen:** Writing – review & editing. **Hein Heidbuchel:** Writing – review & editing. **Lieven Herbots:** Writing – review & editing. **Paul Dendale:** Writing – review & editing. **Bert Vandenberk:** Writing – review & editing, Supervision. **Aaron L. Baggish:** Writing – review & editing, Supervision. **Rik Willems:** Writing – review & editing, Supervision, Conceptualization. **Guido Claessen:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Rik Willems, Jarne de Paepe, Youri Bekhuis reports a relationship with FWO that includes: funding grants. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ajpc.2026.101629.

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