COACHING ASSISTANCE BY PHASE-BASED PERFORMANCE EVALUATION FEEDBACK OBTAINED FROM A SINGLE SACRUM IMU

Mahdi Hamidi Rad[1], Vincent Gremeaux[2], Fabien Massé[3], Farzin Dadashi[4], Kamiar Aminian[1]

[1]Laboratory of Movement Analysis and Measurement, EPFL, Lausanne, Switzerland
[2]Institute of Sport Sciences, University of Lausanne, Lausanne, Switzerland
[3] Gait Up S.A., Lausanne, Switzerland
[4]Huma Therapeutics LTD, London, UK

The main role of a swimming coach is to provide frequent feedback and efficient planning to swimmers during training sessions. Quantitative and objective performance evaluation can better assist the coach. Inertial measurement units (IMUs) are widely used for motion analysis in sports because they can detect a variety of performance-related metrics. In this study, we propose a new performance evaluation feedback using goal metrics extracted from IMU and investigate its effect on the swimmer's weekly progress. The measurement was conducted once per week with 15 competitive swimmers for 10 consecutive weeks using an IMU worn on the sacrum. Each swimmer was asked to swim five one-way laps at maximum velocity in front crawl, and the coach recorded the lap times with a stopwatch, which served as the main representative of swimming performance. The swimmers were divided into two groups, an experimental and a control group, and the coach received phase-based feedback only for the experimental group. The feedback quantified the swimmer's performance in each swimming phase (wall push-off, glide, strokes preparation and swim) and the whole lap in every swimming lap of the test. He then used the feedback to adjust the training for each individual and focus on the weaknesses identified. The results showed that the experimental group had significantly lower lap time (p-value < 0.05) and higher performance regularity than the control group from the sixth training session. This study showed that phase-based assessment feedback can help swimming coaches to create a more efficient training plan through detailed quantitative assessment.

KEYWORDS: IMU sensor, phase-based evaluation, coaching, feedback effect

INTRODUCTION: Swimming is inherently a complex activity because it takes a long time to master due to the many degrees of freedom of movement. Augmented extrinsic feedback has been shown to be beneficial in helping athletes learn complex activities (Sigrist et al., 2013). Thus, the ultimate goal for successful coaching is clear: providing high-quality feedback concurrently or shortly after swimming on a frequent basis. Swimming coaches rely primarily on observation and subjective experience to monitor and evaluate swimmers' performance. However, qualitative analysis is not accurate enough to provide precise information about a swimmer's strengths and weaknesses.

Many studies have extracted kinematic variables from IMU and proved that they are a powerful tool for swimming motion analysis (Magalhaes et al., 2015). However, only some of them have provided the results as feedback to the swimmer or coach (Bächlin et al., 2009; Silva et al., 2011). According to the literature, the use of IMUs to provide feedback is still in its early stages due to the difficulties of collecting data and providing feedback in aquatic environments (Callaway et al., 2009). Using complex multi-sensor networks has led to numerous interventions in normal swimming. In addition, previous studies have rarely made subsequent interventions in the field to show the effects of feedback on performance.

The purpose of this study was to examine the coaching benefits of using feedback based on analysis of swimming phases provided by a single IMU in training sessions. The provided feedback evaluated swimmer's performance in each swimming phase (wall push-off, glide, strokes preparation and swim) and the entire lap to help the coach focus on the weaknesses of each swimmer and guide the training sessions more efficiently. Following a novel approach from our previous study, we first segmented each lap into phases of push, glide, strokes preparation, and swim (Hamidi Rad et al., 2021b). Then, we estimated five goal metrics that had been previously validated to quantify the swimmer's performance in the swimming phases and the entire lap (Hamidi Rad et al., 2021a). For a group of swimmers, a report was given as feedback to the coach, who then adjusted the training for each individual accordingly.

METHODS: Fifteen swimmers from a competitive team (8 men, 7 women, age 14.6±0.7 years, height 171±6 cm, weight 55±9 kg, front crawl record for 50m 28.60 ± 2.04 s) participated in this study. The swimmers all had similar performance levels and were placed on the same team by the swimming club. The swimmers had similar training experiences and trained together regularly six days a week, under the supervision of the same coach. An IMU (Physilog® IV, GaitUp, CH.) was attached to the swimmers' sacrum using a waterproof band (Tegaderm, 3M Co., USA) and recorded 3D angular velocity and acceleration at a sampling rate of 500 Hz. To make the sensor data independent of the position of the sensor on the swimmer's body, a functional calibration was performed out of the water prior to testing (Dadashi et al., 2013). After a brief warm-up period, each swimmer completed five laps of front crawl in one direction at maximum velocity in a 25m pool. Each participant had five minutes rest between two consecutive trials to avoid fatigue. Swimmers completed all swimming phases (push, glide, strokes preparation, swim) to the best of their ability. The lap time was recorded by the coach using a stopwatch. The swimmers were divided into two groups of experimental and control. The lap times from the first test were used as the baseline for dividing the swimmers into the groups. The two groups were selected to have similar performance level, age range, weight, height, and gender (experimental group: 4 males, 4 females, age 14.5±0.5 years, height 170±6 cm, weight 55±8 kg, control group: 4 males, 3 females, age 14.6±0.4 years, height 171±7 cm, weight 55±7 kg). The same measurement was repeated once a week for 10 sessions and the coach received feedback only for the experimental group swimmers after each test.
Validated algorithms from our previous study (Hamidi Rad et al., 2021a) were used to estimate the goal metrics of push maximum velocity, glide end velocity, strokes preparation, swim and lap average velocity, and stroke average velocity for each swimming lap. The graphs for individual performance per session and in multiple sessions and the comparison of swimmers per session were the three types of feedback provided to the coach for the swimmers in the experimental group. An example of the individual feedback is shown in **Figure 1**. The performance evaluation spider chart (**Figure 1**-left) shows one goal metric on each axis for the five laps (L1 to L5). The average and best achieved performance of each axis during the five laps are shown in light and dark green graphs, respectively. The stroke average velocity diagram (**Figure 1**, right) illustrates the average velocity per stroke during the five laps. It shows the values of the velocity variations of each lap in the legend. The individual multisession result included the swimmer's average performance graphs from the previous sessions to show the progress trend. Finally, as a third type of feedback, the average performances of all swimmers were displayed on the same graph for comparison. The coach was asked to illustrate his findings from the feedback and write down the training changes based on them for each swimmer for the next week.
We compared all lap time values of the two groups in each test session. First, the normality of the data distribution was checked using the Kolmogorov-Smirnov test and then an independent t-test was performed for comparison (p-value < 0.05 as significant). The standard deviation of the groups' lap times per session was also compared. The standard deviation of the five lap times for each swimmer was calculated, averaged over the group, and then compared to the other group. The Mann-Whitney U test is the nonparametric method (Mann and Whitney, 1947) used for this comparison with a confidence level of 95%.

RESULTS: After confirming the data normality by Kolmogorov-Smirnov test, an independent t-test was performed to compare the groups. The groups showed significant differences from the sixth session onward (**Table 1**). The standard deviation of the groups also showed a significant difference after the sixth session (except for the 8th session) (**Table 1** and **Figure 2**).

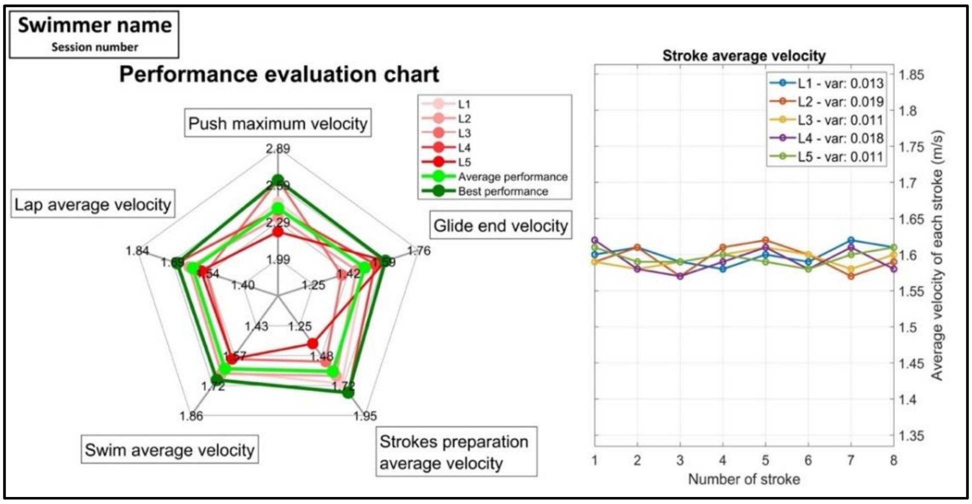

Figure 1: ***Example of individual feedback. The performance evaluation chart (left) shows the goal metrics for five laps (L1 to L5), average performance (light green), and best performance (dark green). The stroke average velocity chart (right) shows the average velocity of each stroke during five laps and its variation on the legend.***

Table 1 – Session-level comparison between the experimental and control groups. t-score and U-score results for comparison of mean and standard deviation (Std) lap times, respectively.

# Test session	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Lap time comp. : t-score	0.27	1.62	1.36	1.81	1.12	**2.39***	**2.79****	**2.09***	**2.40***	**1.99***
Std comp.: U-score	25	18	17	16	10	**9***	**7***	13	**5***	**9***

***p-value < 0.05, ** p-value < 0.01**

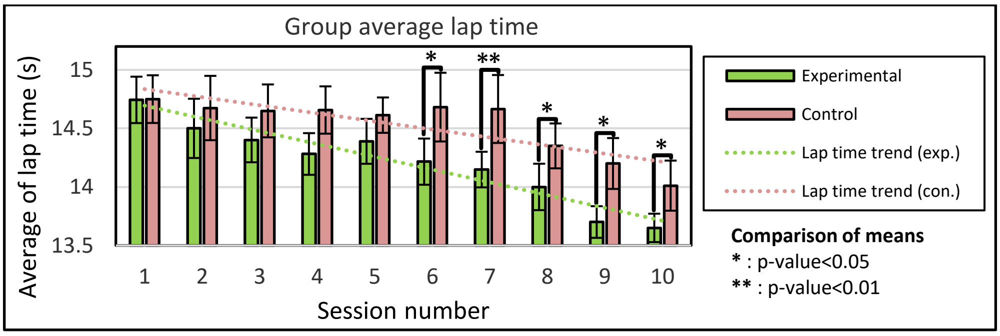

Figure 2: ***Average and standard deviation of lap times for the experimental (exp.) and control (con.) groups during 10 sessions***

From coach reports collected during the measurements, it appears that he used all three types of feedback. He emphasized training the weak phases until the next evaluation. He assumed that each training strategy was effective after three weeks. If progress was satisfactory, he continued training in the same way; otherwise, he chose a new training for the swimmer.

DISCUSSION: By directly observing the individual performance evaluation chart (**Figure 1**, left), the coach was able to determine the swimmer's potential best performance and clues for improvement at each phase of swimming (by comparing the swimmer's average and best performance). The coach also paid attention to the results of a combination of phases so that improvement in one phase did not lead to deterioration in the other phases. The graph of Stroke average velocity (**Figure 1**, right) showed a lack of stroke regularity in the swim phase for some swimmers. He also noticed the effects of incorrect breathing pattern on this graph. The coach noticed a decreasing trend of velocity of strokes, which is a sign of lack of endurance. With the third type of feedback, the coach identified the weaknesses and strengths of each swimmer by comparing them to the others. Observing how each swimmer responded to the new training helped the coach understand the swimmers' potential.

The two groups showed an insignificant difference of lap time average and standard deviation during the first testing session (**Figure 2**). The average lap time of the two groups start to differ from session 2 (by 0.17s), and the difference increases during the next sessions (more than 0.5s in sessions 7 and 9). Relative performance of the experimental group with respect to the first session (baseline) increases from 1.6% in session 2 to 7.4% in the last session while the same value changes from 0.5% to 5.0% over the test period for the control group. The results show that the average lap time and standard deviation of the experimental group are significantly lower than those of the control group after the 6th session. This shows that the swimmers in the experimental group not only swam faster, but also swam more consistently than the control group. We could provide feedback on all phases of swimming and not just the swim phase and the coach was able to obtain a more comprehensive performance evaluation. In addition a single IMU on sacrum, which can be integrated into the swimsuit does not affect the swimmer's normal performance and can be used for daily training as we had no complaints after several sessions from the swimmers about feeling higher drag or discomfort.

CONCLUSION: In this study, we examined the effect of coaching guided by phase-based performance evaluation feedback on swimmers' performance during 10 weeks of training. The coach received feedback for the experimental group and adjusted the training accordingly. The results showed that the performance of the experimental group significantly outperformed that of the control group in terms of lower average lap time from the sixth training session. In addition, the swimmers in the experimental group swam more regular lap times than the control group. The coach used the phase-based feedback from IMU as an aid to obtain an objective and quantitative assessment and to guide the training sessions more efficiently. He found the feedback reports very helpful in "diagnosing" the swimmers' weaknesses and monitoring their progress during the training sessions. Integrating the IMU sensor into the swimsuit and providing real-time feedback are the next steps toward a new swimming analysis system.

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