Project Report:
Under Armour’s Armour 39 challenge

Hosted by NineSigma

Proto:
Under Armour 4 Runners (UA4Runners)

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Concept

UA4Runners aims at creating a new level of engagement between runners and the Armour 39 platform. The idea behind UA4Runners is to provide a single tool able to provide objective assessment of physical recovery and cardiorespiratory fitness, as well as personalized coaching.

Functionalities Overview

UA4Runners offers three main functionalities:

- Personal Trainer
- Physical Condition & Recovery State Monitoring
- VO2max Assessment

Role of the Personal Trainer is to create personalized training programs based on the user target race (10K, half marathon, full marathon), target time, current condition (optional) and training days, as well as to provide advice and modify scheduled trainings based on objective assessment of the user condition.

Objective assessment of the user condition (physical condition & recovery state) is performed using the Armour39 platform and computing heart rate variability features from the received RR intervals. HRV is translated into a “user-friendly” number between 0 and 10.

Finally, UA4Runners can estimate level of cardiorespiratory fitness by analyzing heart rate during the user’s training. Thus, without requiring additional tests.

Functionalities Details

Personal Trainer

Role of the Personal Trainer is to create personalized training programs based on the user target race (10K, half marathon, full marathon), target time, current condition (optional) and training days, as well as to provide advice and modify scheduled trainings based on objective assessment of the user condition.

Training Program

Based on the current condition, the Personal Trainer will determine a feasibility score and schedule all trainings until the race date. The Training Program created by the Personal Trainer follows standard training programs used my semi-professional and professional endurance athletes, consisting of N cycles of 4 weeks, 3 weeks consisting of trainings at increasing or high training load, and one week of recovery at 60-70% of the training load.

The Training Program will consist of normal, progressive, short intervals, long intervals, and long trainings. Each training is divided into training phases (e.g. warm up, intervals, cool down). A training phase can be either target time or target distance. Target distance means that a certain distance needs to be reached in order to switch to the following phase (e.g. 1 mile), while target time means that the phase will last N minutes regardless of the distance covered. The Personal Trainer will assign a target pace to each phase and training type and update your target paces every training cycle.

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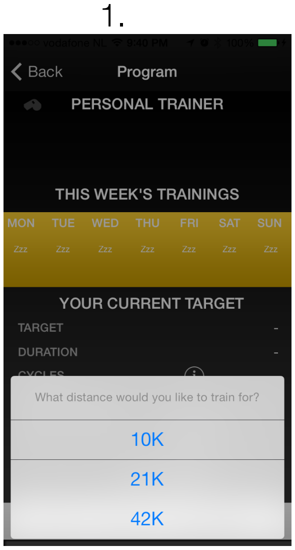

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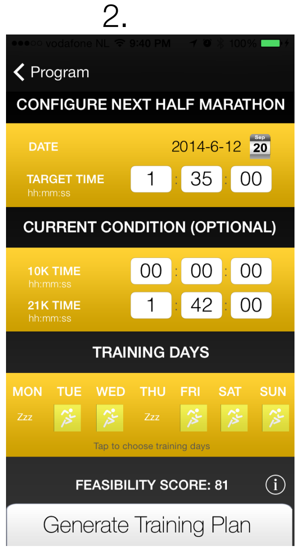

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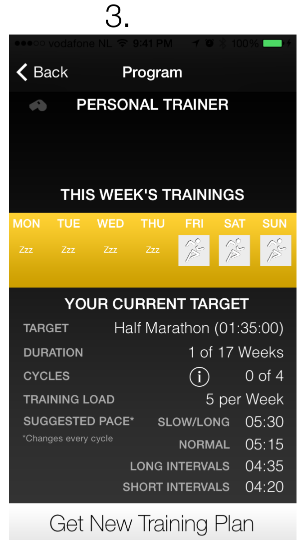

1. Target race choice. 2. Half marathon target configuration. 3. Cycles and paces for the current cycle.

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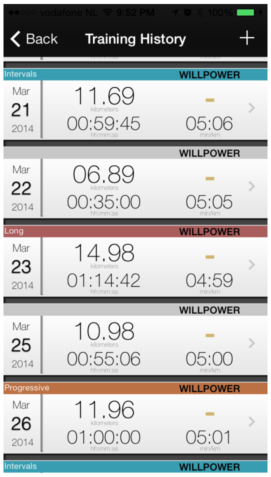

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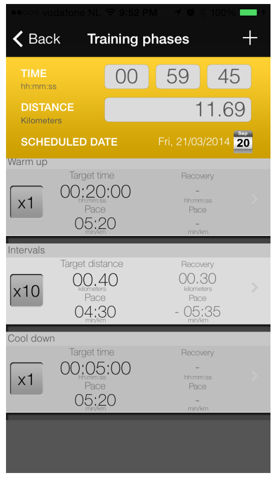

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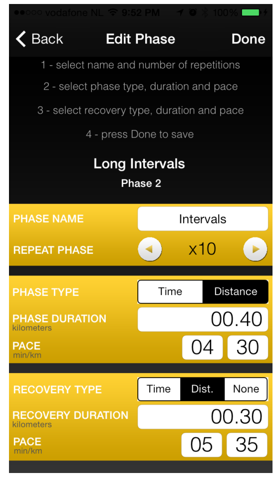

4. Scheduled trainings generated by the Personal Trainer. 2. Example of interval training and training phases, including repetitions and recovery time. 3. Details of the intervals phase for the intervals training, target distance and target pace, number of repetitions, all details can be edited.

Each training will be evaluated by the Personal Trainer based on your actual pace and the target pace of each phase. The Personal Trainer will provide you feedback on your trainings. Training tracking is based on GPS data (the Armour39 platform is configured every time a training starts using the most recently updated information about the user weight and either age-predicted or measured maximal heart rate). GPS data is buffered and filtered by accuracy level, reported distances are normally off by 50-100 meters every 10 km (i.e less than 1% error).

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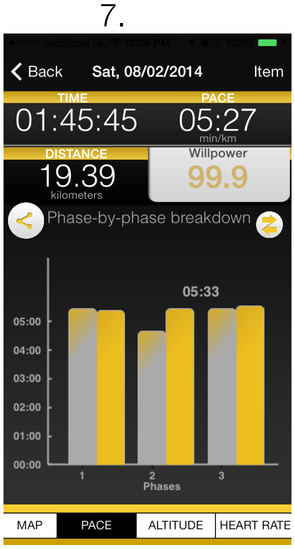

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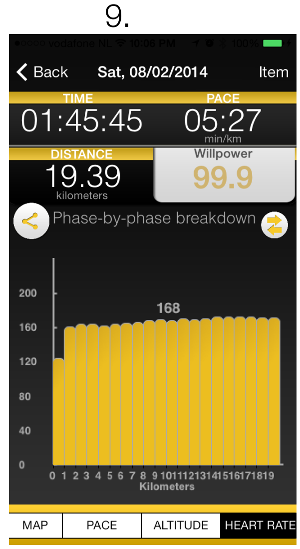
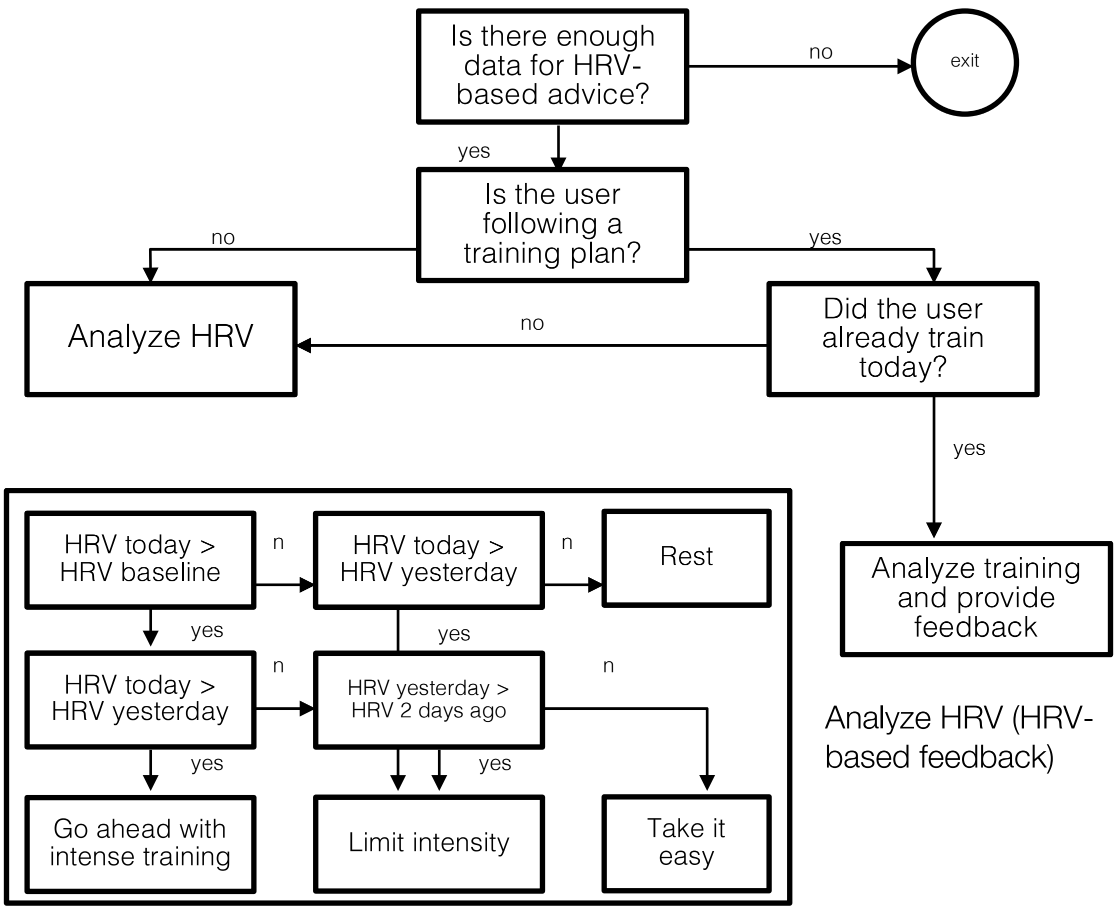


7. Phase by Phase breakdown for a training. Target pace is shown in gray, actual pace in gold. Differences between target and actual paces for each phase are used by the Personal Trainer to evaluate a specific training. 2. Map detail for a training, showing kilometers annotations. 3. Heart Rate and WILLPower as recorded from the Armour39 platform.

HRV-based Advice

The Personal Trainer can analyze your physical condition & recovery state (see next section) and use your HRV-derived condition results over the past week (at least 5 days required) to adapt your training program. In case you have no training program, the Personal Trainer will suggest how to train on that specific day based on HRV only (e.g. rest, take it easy, train but limit intensity, go ahead and train hard).

If the user configured a training program, the Personal Trainer can modify it according to the user condition. More specifically, in case of negative trend the Personal Trainer will suggest either to reduce training intensity (and modify the daily training reducing pace by 10%) or to move the training to the following day or to cancel the training for that specific day.



Flow diagram of the Personal Trainer actions and HRV-based training. HRV-based feedback is roughly based on [1].

Physical Condition & Recovery State Monitoring

Objective assessment of the user condition (physical condition & recovery state) is performed using the Armour39 platform and computing heart rate variability features from the received RR intervals. HRV is translated into a user friendly number between 0 and 10, used by the Personal Trainer to optionally modify the current training program based on the user's condition.

Short-term changes in HRV features, used to assess training load and recovery, seem to be a reliable measure. Most research was able to show a significant relation between HRV features and training load/performance, with some studies showing that HRV-guided training can be used to increase VO2max faster [1,2,3].

HRV analysis is implemented on the phone. RR-intervals are received from the Armour39 platform, corrected for artifacts (removal of each interval differing more than 20% from the previous one) and buffered in a 60 second window used to extract HRV features. Accuracy of the Armour39 in detecting RR intervals was also tested against other monitors and a full ECG (not shown). Time (AVNN, rMSSD, SDNN, pNN50) and frequency (LF, HF, LFHF) features are extracted. Frequency features are extracted after linear interpolation of the RR-intervals (otherwise having non-constant frequency), hamming windowing and removal of the DC component. At the moment only rMSSD (normalized and corrected for age differences) is used to assess physical condition, however HF might be another good option according to literature.
To improve reliability of the test (by maintaining constant the effect of respiration during different recordings), paced breathing is guided during the test.

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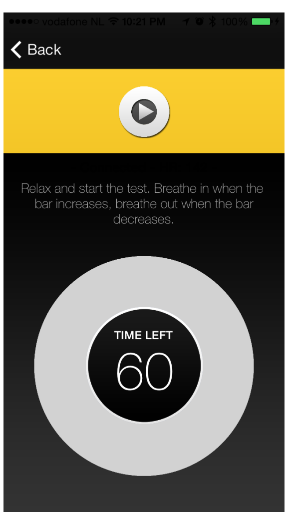

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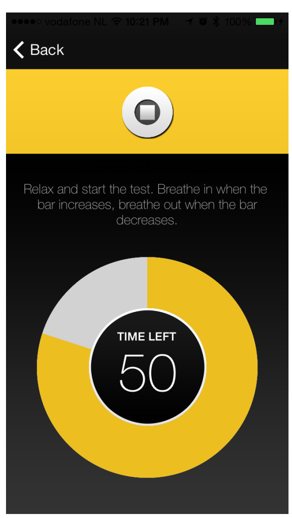

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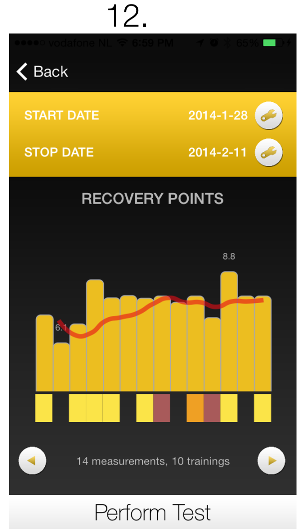

10-11. 60 seconds Heart Rate Variability analysis to determine recovery state. 12. Two weeks of recordings, moving average overlaid to highlight trends in physical condition. Trainings recorded using the app are shown at the bottom (color coded by willpower value).

VO2max Assessment

UA4Runners can estimate level of cardiorespiratory fitness by analyzing heart rate during the user's training. Thus, without requiring additional tests.

VO2max is estimated according to the principles behind sub-maximal VO2max, meaning that the heart rate at a constant workload should be representative of the user fitness (lower HR at the same intensity for more fit subjects). The formula used is the one reported in [4], since it was developed using sub maximal running speeds (< 7.5 mph for male and < 6.5 mph for female), and includes speed as a parameter, which means that any training can be used for VO2max estimation regardless of the speed the user is comfortable with. Additionally, UA4Runners implements an age-adaptation factor since the original formula was developed on college-aged individuals and would overestimate significantly VO2max for older persons.

UA4Runners analyzes HR data received from the Armour39 platform during training, and is able to locate periods of stationary heart rate (based on the coefficient of variation) as well as constant speed. During these phases, HR and running speed are isolated and used to estimate VO2max for a specific training. Other small correction concern discarding the first 5 minutes of data (hardly possible to reach steady state) and remove everything beyond one hour of training, since the effect of fatigue would increase heart rate for the same speeds.

UA4Runners updates the current VO2max using the estimates of the last 2 weeks, reporting categories based on age and gender.

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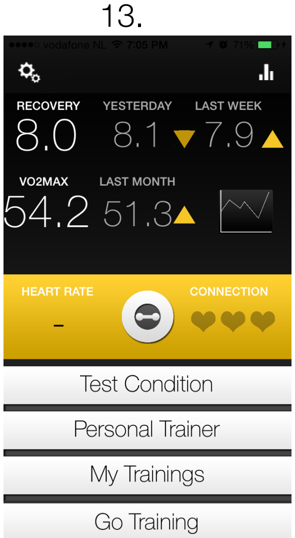


14.

13. Home screen reporting current and past estimated VO2max. 14. VO2 max weekly progress and user category based on age and gender.

Other Functionalities

In addition to the main features highlighted in the previous part of the document, UA4Runners can track the following:

- Calories (based on data received from the Armour39 platform)
- Altitude (+altitude profile in the training view)
- Maps (+km/miles annotations and times)
- Voice component (coaching during training, guiding you through the different phases of each advanced training without worrying about checking your phone or remembering them – works also in the background)
- All sort of plots (vo2max, condition trends, kilometers/miles, pace, number of trainings and time run each week and month, etc.)
- Age predicted HR max + update using training data
- Export of trainings data (csv file including distance, time, pace, altitude, latitude, longitude, willpower and heart rate)
- Automatic stop based on acceleration (currently disabled – some background issues)

Future Opportunities

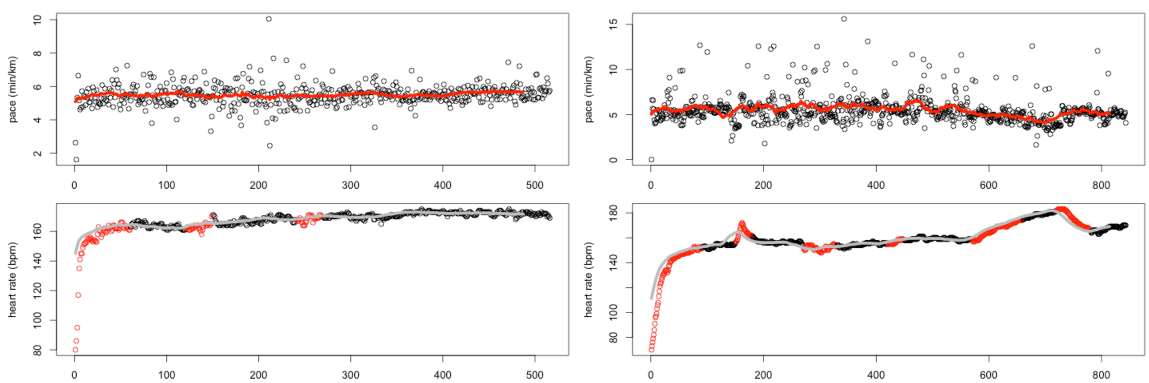
Due to time limitations I did not implement the following features, however I believe they could be meaningfully integrated with some effort:

- Better integration with willpower (I don't have enough data – just some recordings on me – to understand exactly how to better integrate willpower with the Personal Trainer, but I think the Personal Trainer could give target willpower points for each training depending on the intensity and cycle week)
- If the app goes public, it would be great to collect data from many users on willpower of each training + recovery time (HRV scores) and build personalized models of how each training (and intensity expressed as willpower) affect physical condition and recovery (expressed in terms of HRV), and therefore be able to predict more accurately recovery time, even in terms of precise time to recovery (as well as provide training plans that better fit the specific user)
- I'd be particularly interested in measuring autonomic control recovery after exercise, which means measuring HRV every X minutes after training to see how long it takes to get back to pre-training values (depending on training intensity and fitness level this would change significantly, and I guess it could be used also to monitor cardiorespiratory fitness improvements)
- Ventilatory threshold estimation (literature showed that it can be estimated using HRV during training)
- Extension to other sports (e.g. biking)

Preliminary Data

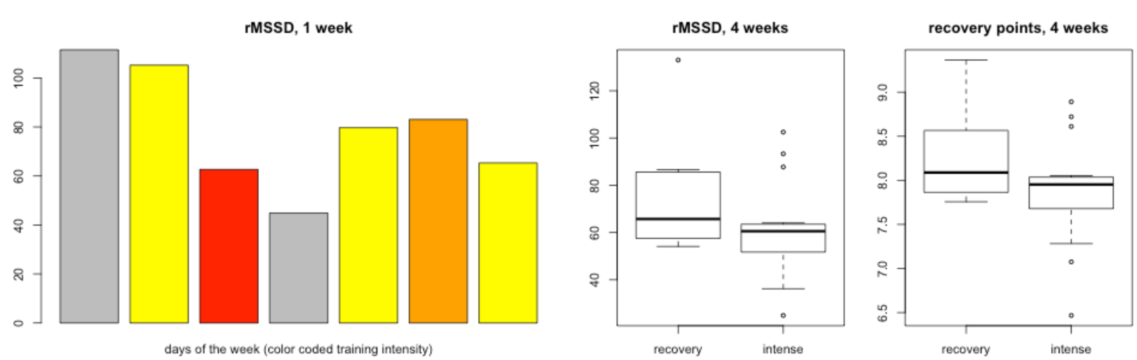
VO2 max estimation

VO2 max estimation for two trainings of different duration and intensity is shown in the following plot. The two plots on the left are 19.5 km at slow intensity, the two plots on the right show 7 km at higher intensity with 1 final km full speed (see pace plots, top row, with reduced pace – i.e higher speed – towards the end). Heart rate (bottom plots) shown in red is discarded since the coefficient of variation is too high, highlighting non-stationary heart rate which would result in wrong vo2max estimations (for example during the first minutes speed can be as high as later on, but heart rate is still low, thus vo2max would be overestimated). VO2max estimated is 54 for the left plots and 55 for the right plots, higher intensity might lead to higher accuracy, however results are very similar.



Physical Condition & Recovery State

Recovery Points are extracted from rMSSD (even though HF power might be a better choice). The following plots show rMSSD for an example week, trainings are color coded to show daily variability, e.g. decrease on the third day after training the second day, and further decrease after intense training on the third day. rMSSD increases again after 1 day of rest (gray bar in the middle of the week). The two boxplots show longer term analysis, where 1 cycle of 4 weeks (3 high intensity 1 recovery) is used to compare rMSSD and derived recovery points over the period. Average recovery points are 7.8 during intense training and 8.3 during the recovery week, showing improved condition with reduced training load.



References

[1] Kiviniemi, Antti M., et al. "Endurance training guided individually by daily heart rate variability measurements." European journal of applied physiology 101.6 (2007): 743-751.
[2] Garet, Martin, et al. "Individual interdependence between nocturnal ANS activity and performance in swimmers." Medicine and science in sports and exercise 36 (2004): 2112-2118.
[3] Pichot, Vincent, et al. "Relation between heart rate variability and training load in middle-distance runners." Medicine and science in sports and exercise 32.10 (2000): 1729-1736.
[4] George, James D., et al. "Development of a submaximal treadmill jogging test for fit college-aged individuals." *Medicine and science in sports and exercise*25.5 (1993): 643-647.