# Athlete and coach perceptions of technology needs for evaluating running performance

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**Abstract**

Athletes and their support team utilise technology to measure and evaluate technique and athletic performance. Existing techniques for motion and propulsion measurement and analysis include a combination of indirect methods (high-speed video) and direct methods (force plates and pressure systems). These methods are predominantly limited to controlled laboratory environments (in a small area relative to the competition environment), require expert advice and support, and can take significant time to evaluate the data. Consequently, the more advanced measurement techniques are considered to be restricted to specific coaching sessions, or periods in the year leading up to competition, when the time and expertise of further support staff are available. The more widely used, and simple, devices for monitoring 'performance' during running include stopwatches, GPS tracking and accelerometer-based systems to count strides. These provide useful information on running duration, distance and velocity but lack detailed information on many key aspects of running technique. In order to begin the process of development of more innovative technologies for routine use by athletes and coaches, a study was required to improve the understanding of athletes' and coaches' perception of their requirements from measurement technology. This study outlines a systematic approach to elicit and evaluate their perceptions, and presents the findings from interviews and a questionnaire. The qualitative data are presented as a hierarchical graphical plot (structured relationship model) showing six general dimensions (technique, footwear and surface, environment, performance, injury and cardiovascular) and shows the development of these general dimensions from the interviewee quotations. The questionnaire quantitative data enhances the study by further ranking characteristics that arise from the interviews. A contrast is shown between short and longer distance runner groups, as might be expected. The current technology available to elite runners is briefly reviewed in relation to the 22 characteristics identified as important to measure. The conclusions highlight the need for newer technologies to measure aspects of running style and performance in a portable and integrated manner, with suggestions as to size and weight likely to be acceptable to users for emerging devices.

**Keywords:** Perceptions, Instrumentation, Gait Analysis, Running Performance

Word count: 7400

## 1. Introduction

Currently many athletes and coaches tend to rely on a combination of visual observations and simple timing data to evaluate technique and performance respectively. This highly subjective and ‘expert’ driven approach is limited to the athletes’ and coaches’ interpretation of observed actions that can last fractions of a second. In addition, when the athlete is training without the coach a form of self assessment or reportable measurement may be desirable. A systematic approach to analyse running can be achieved by using video analysis and also ground reaction force measurements. Many potentially useful measurement techniques have been developed over the past 20 years (including pressure/force measurement systems and high speed video capture). These can provide relatively detailed gait information including forces, pressure distribution, joint angles, running velocity and other characteristics. However, there are often limitations in such measurement techniques including resolution, accuracy, portability, analysis time, additional specialist advice, and cost amongst many. Consequently, it was considered the case that regular widespread use of many measurement and analysis techniques, outside of research applications, appeared to be relatively limited. The most obstructive factor was thought to be the expertise and time required to operate and evaluate any complex tools and data, and perhaps a lack of knowledge of users regarding the potential benefits to the user.

Figure 1 shows a hierarchical diagram illustrating the key factors identified as influencing running performance (Hay and Reid, 1988). This simplified model demonstrates that the underpinning factors connected to performance are foot contact forces and their respective duration of application during the surface initial contact and subsequent take-off phases. Additionally, in terms of applications within injury management (De Cock et al, 2008; De Cock et al, 2005; Dixon, 2006), it was considered that more detailed knowledge of the typical foot load *distribution* for an individual athlete may be more pertinent. However, determination of the variables and factors of key interest to coaches and athletes remained to be established and the gathering of this knowledge and understanding forms the focus of this paper.

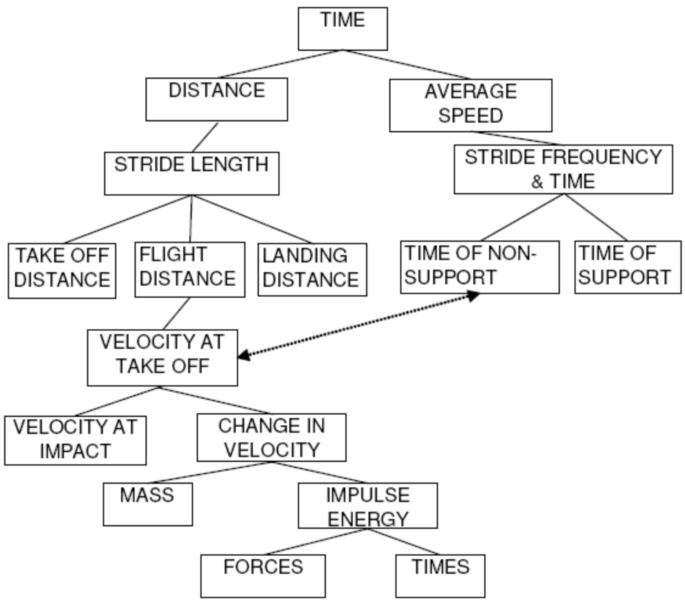


**Figure 1: Simplified Running Model (adapted from Hay & Reid, 1988)**

With rapid improvements in sensor technology, wireless transmission and data analysis techniques, it is envisaged that a (novel) device capable of measuring real-time meaningful information on running technique, in a readily accessible format for the coach and athlete, should now be achievable. No research literature was identified that concluded or specifically focussed on what is required from technology from the user perspective, and furthermore in what form it should be delivered to provide readily accessible and practical data to the athlete and coach. However, references were found that demonstrate specific advances in technologies for monitoring user loading in shoes (Heller et al, 2004).

This paper outlines the findings of a focussed study to elicit the perceptions of elite athletes and coaches with regard to their own needs and preferences for technology in their day-to-day evaluations of performance. The aim of the study was to identify, from elite level athletes and coaches, the important characteristics of running technique and performance that they consider would provide useful feedback for training and/or competition.

No previous studies exploring the perceptions of running technique from which a suitable methodology could be drawn were identified in the literature, however previous methodologies used to investigate perceptions of users to their sports *equipment* (Roberts *et al.,* 2001; Fleming *et al.,* 2005) were considered appropriate. These studies had shown a propensity towards the use of surveys and/or interviews within a qualitative analytical framework as the primary data collection method, and were deemed successful in identifying participants' opinions and preferences regarding aspects such as feel and performance of their equipment.

The findings will be used to focus future research aimed to produce routine systems capable of measuring, recording and presenting detailed information to the athlete and coach during their training and/or competition. The objective of the developed technology is to assist the athlete (and their team) to improve performance and aid management of rehabilitation from injury.

## 2. Study Design Methodology

A subject-led semi-structured interview was considered suitable for eliciting athlete perceptions, since this permits investigation of selected issues in depth and detail (Patton, 1990). However, since this approach is restricted by its qualitative nature, only limited statistical analysis is possible. Therefore, a combination of this approach with a quantitative method (survey questionnaire) was identified to reduce the disadvantages of each.

Firstly, interviews were used to elicit subject-led responses and minimise investigator expectations and/or bias, and were primarily individual (i.e. one investigator and one participant). In addition two group sessions were undertaken with one interviewer and between 4 and 6 participants. These tasks were followed by the production of a questionnaire developed from the responses in the interviews. The objectives of the interview phase were to elicit undiluted information that was rich in depth and detail from which selected themes could be chosen for further investigation. Allowing the participants to lead the interview ensured accuracy of matters significant to the participant and reduced the risk of investigator bias, through preconceptions. The objectives of the questionnaire were to further assess the themes obtained from the interviews by rating their relative importance to the athletes and coaches, with a larger number of respondents and hence more (statistical) validity.

### *2.1 Data Collection*

Data were collected through one-on-one interviews and two group seminars with a selected list of athletes and coaches. An interview guide was produced to aid the investigator and optimise the amount of data obtained from each session. The guide provided a selection of unambiguous questions and ensured that a consistent approach was followed. Prior to the development of the interview guide several elite coaches and a performance analyst were consulted as to its design and content (including the prompts). Additionally, a series of leading questions were included at the end of the guide to help prompt athletes and coaches that were having trouble articulating their responses. If this prompt was used a note was made for that question and subject. The start question used to begin each interview was:

> *"With improving technology we have the ability to measure many aspects of running technique and performance. What information would you find beneficial?"*

An approach known as 'purposeful sampling' (Patton, 1990) was used to select the participants for this study. Purposeful sampling targets participants from which one can learn about issues of central importance to the purpose of the study. It was envisaged that elite athletes and coaches would provide a relatively high quality of response due to their higher level of skill/ability and better understanding of factors influencing their performance than those of average ability. Therefore, for this study, only elite (national standard or better) athletes and coaches (trained an athlete to national standard or better) were selected. In order to further classify the subjects into groups their age, event, personal best and gender were recorded.

Initially, from previous perception studies with elite performers (Scanlan *et al.*, 1989a, 1989b; Hocknell et al., 1996; Roberts *et al.,* 2001), it was considered that a minimum sample size of fifteen was required for this study. However, this research involved a group of athletes and coaches from different events, with potentially varying views and requirements, so 20 participants was identified as a minimum number of subjects, with an even spread of events between sprints, mid- and long-distance. A continual review of the emerging information was, however, undertaken and when it was clear that no new themes were emerging (saturation point had been reached) it was decided to conduct a further four interviews in the interest of completeness and to confirm no new information was elicited. The final number of interviews was 22.

During the interviews the investigators took careful notes of the conversations and quotes, where appropriate, rather than making verbatim transcripts from recordings of the sessions. The participant led the interviews, and the investigator had ample opportunity to make note of the necessary details and avoid the use of a recording device. On the occasion that the interviewer had problems following the comments he would ask the participant to repeat their point(s). In comparison to a previous study (Fleming *et al.,* 2005) this method was very much quicker than transcribing recordings, and was adjudged to provide sufficient quality and detail of feedback from the participants for this study.

Ethical approval was obtained in accordance with Loughborough University requirements and prior to the interviews a full explanation of the project was given to each participant along with the option to terminate the interview at any time. The athletes were informed that their responses would remain anonymous and that their information would only be used for this study (including publication). All detailed notes are to be destroyed at the end of the project.

### *2.2 Data Analysis*

The raw perception data (response quotes and statements) were organised into a set of meaningful structured themes by means of the technique 'inductive analysis'. This involved obtaining categories and themes from the quotes themselves rather than forcing them into pre-determined groups. The analysis followed the procedure developed by Scanlan *et al.,* (1989) which began with each interview transcript (produced from the notes of the interview) being read and analysed. This increases familiarity with the interview data and helps identify the emerging themes. To further aid analysis, the software package QSR-N6 NUD*IST (QSR International Pty Ltd, 2000) was also used to identify and group each emergent theme. Once emergent themes had been identified and grouped into ‘dimensions’, the next phase was to develop the hierarchical structure and show links between sub-themes and dimensions. From the establishment of these dimensions and the base themes a questionnaire was than able to be developed to quantify their importance for a larger data set of respondents.

### *2.3 Questionnaire Design*

The questionnaire was designed using terminology and prompts (from keywords elicited during the interviews) to reduce the risk of misinterpretation from the subjects. The questionnaire was split into four sections.

The first section obtained background information on the participant including their age, main event, personal best performance, training frequency and gender. This provided background information on the participant to confirm their suitability for the study and allowed analysis of the results, where warranted, into categories such as event and gender.

The second section focused on identifying how useful information on, or measurement of, each of the twenty two identified base themes (or characteristics) is or would be to the participant. A scale of 1 to 7 was used to rate each theme, with 1 as ‘not very useful’ and 7 ‘very useful’, chosen as previous studies had identified this as a suitable number of options for the participant to select from (Roberts *et al.,* 2001, Fleming *et al.,* 2005).

The third section investigated opinions relating to the physical and operational aspects of a measurement device that they might use. This section was aimed to understand any preference for size or weight limits, and for preference as to the way measured data should be presented and how quickly.

The fourth section identified the participant's general opinions on current measurement technology in general and experiences of what devices they had used in the past.

## 3. Results

This section is split into two parts, comprising both the results from the qualitative interview and quantitative questionnaire data collection methods.

A total of 28 athletes (age 18 to 31 years, 16 male and 12 female) and 5 coaches were initially interviewed individually, with an additional 6 athletes (age 17 to 24) and 4 coaches providing their comments in two group sessions. The interviews lasted approximately 15 minutes and resulted in around a 10 page transcript of notes.

The themes that emerged as part of the inductive analysis of the participants' responses were grouped together to form the dimensions. Each dimension was formed from a hierarchy of sub-themes derived from participant quotes. Relationships between the dimensions were identified and a 'structured relationship model' was produced to show the hierarchy and any interconnecting relationships. From the development of the emergent themes, 22 specific characteristics were identified and these were further explored via a questionnaire. The questionnaire enabled a larger sample of participants to be investigated (n = 62).

The six general dimensions that emerged from the inductive analysis of the interview responses were determined as:

1. Technique
2. Footwear and Surface (or Equipment)
3. Environment
4. Performance
5. Injury
6. Cardiovascular

The structured relationship model produced is shown in Figure 2, and visually represents the hierarchical structure of each dimension. It illustrates how the athlete and coach responses, through levels of clustering, form the base themes and sub-themes and eventually form the general dimensions. It was found that some quotes could be placed into more than one dimension; hence inter-dimensional relationships are also illustrated.

The terminology used in expressing the responses is a direct outcome of the language used by the athletes and coaches. Clarification of some words and terms is given, where necessary, to help the reader understand their meaning within the context of the statement. Quotations are also used throughout this section to illustrate the language used and points made.

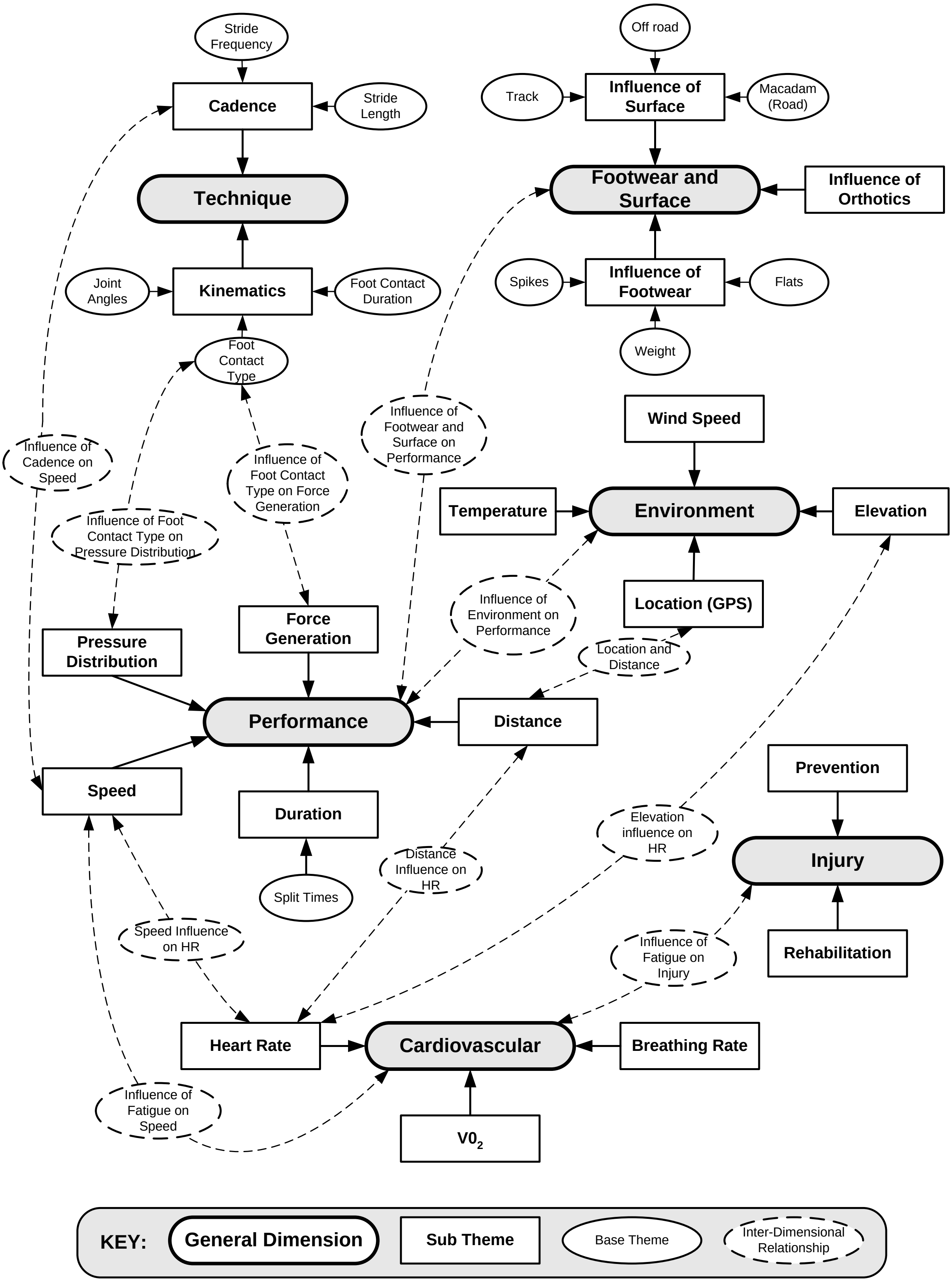

**Figure 2. Structured Relationship Model of the 6 general dimensions derived from the analysis of athlete and coaches responses to interview.**

## *3.1 Qualitative Analysis*

This section describes the 6 general dimensions; technique, footwear and surface, environment, performance, injury and cardiovascular. The 6 dimensions are illustrated in the structured relationship model (Figure 2) which also shows the link between each dimension established during the inductive analysis of the interviews. A tree diagram is presented for each dimension which illustrates a range of quotes from each base theme. These quotes are from a base of often hundreds, chosen to highlight for the reader representative examples.

### *3.1.1 Technique*

For the general dimension 'technique' (see Figure 3) the base themes were identified by the participants as crucial aspects of running technique and indeed running speed as illustrated by the inter-dimensional link between the two. Many participants identified monitoring cadence (steps per minute) as an essential aspect of running technique.

The sub-theme kinematics was split into three base themes of joint angles, foot contact type and foot contact duration. Joint angles were mentioned in relation to mainly the lower limbs (ankle and knee) and identified as potentially useful feedback information as an aid during training. The base theme of ‘foot contact duration’ was mentioned as another useful measure of running technique. It was generally mentioned that a shorter contact time was preferable for better performance.

The base theme ‘foot contact type’ was commonly mentioned with quotes relating to midfoot, rearfoot and forefoot running styles. Comments were also made relating to inversion (supination) and eversion (pronation) of the foot.

Foot contact type was also raised as a factor in both the relationship between pressure distribution and force generation. Several participants identified that different foot contact types would result in differences in kinetic and kinematic performance during contact with the ground hence two inter-dimensional relationships are shown in Figure 2.

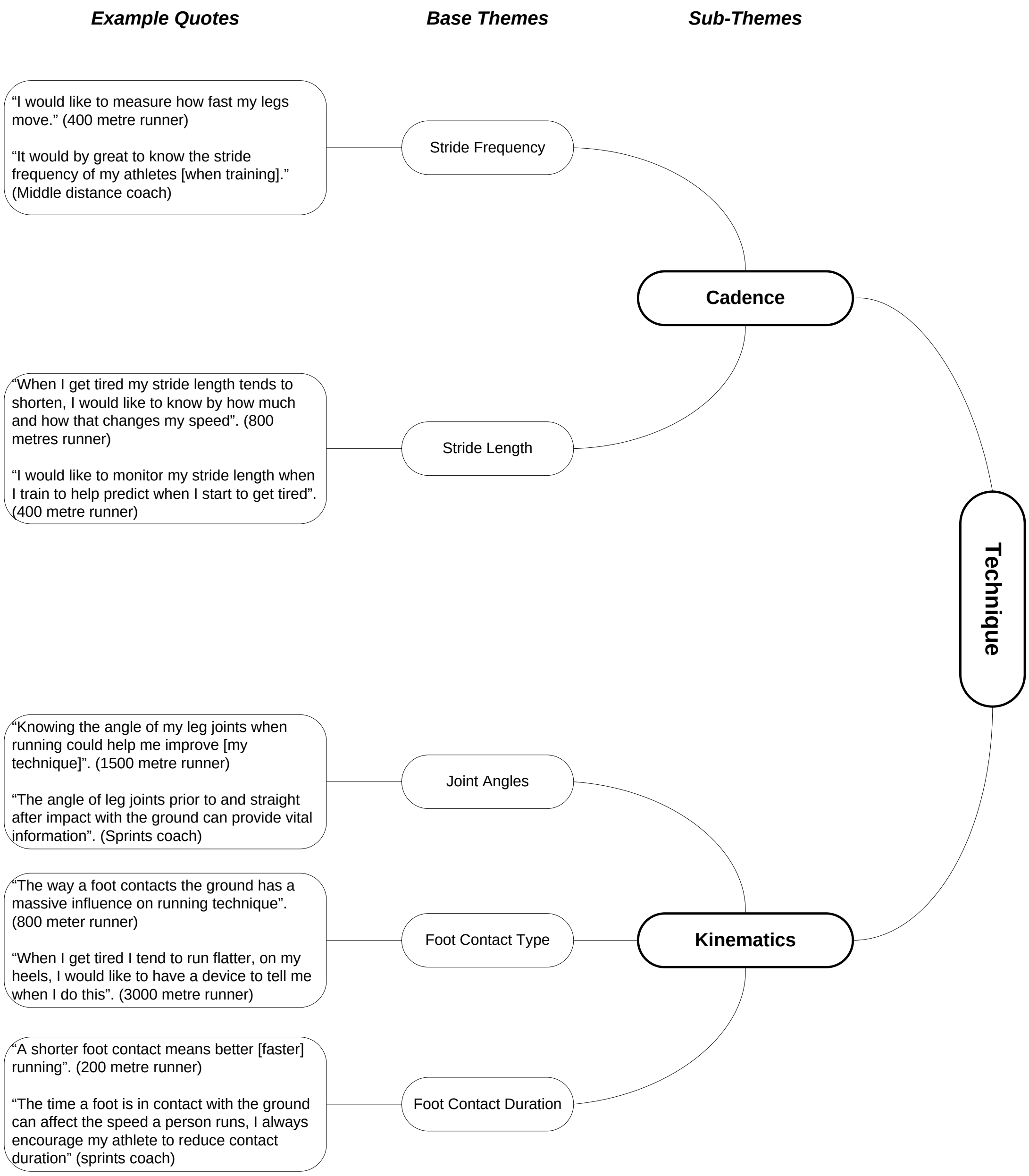


**Figure 3 – A tree diagram for the dimension ‘technique’**

### *3.1.2 Footwear and Surface*

The dimension of ‘footwear and surface’ (see Figure 4) was split into three sub-themes defined as the surface, footwear and orthotic (insoles) influences. These sub-themes were commonly mentioned in relation to how they could influence running performance, hence one inter-dimensional relationship is illustrated between the two dimensions in Figure 2.

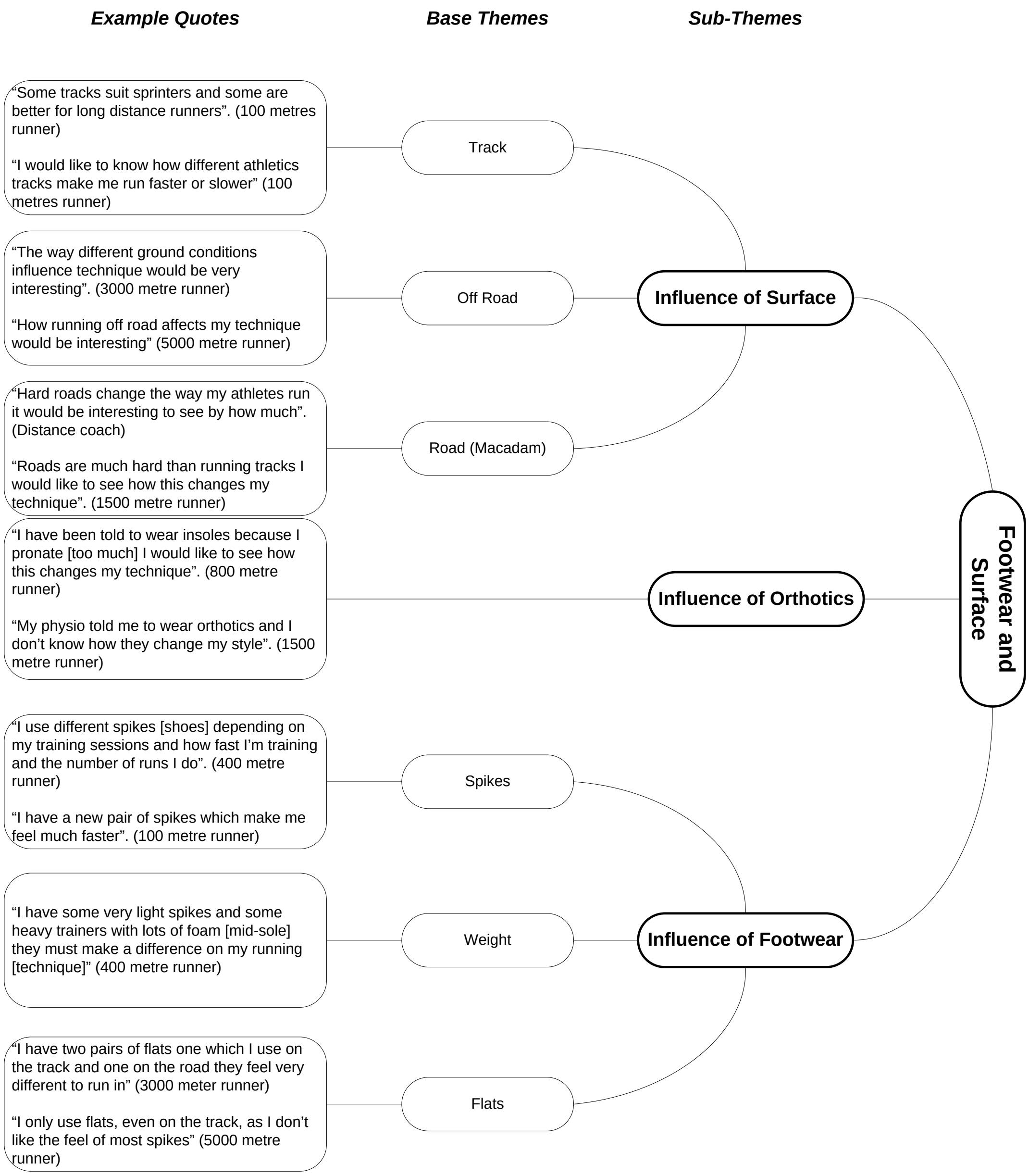


**Figure 4 – A tree diagram for the dimension ‘footwear and surface’**

### *3.1.3 Environment*

The dimension ‘environment’ (see Figure 5) explained external environmental influences that could be measured to help analyse running performance. It was divided into four sub-themes; temperature, wind speed, elevation (altitude) and location. Each sub-theme was identified in the feedback as a way of helping to assess training performance. Wind speed was recognised by the participants as influencing training sessions and a method of quantifying both the magnitude and direction of this was identified as beneficial. Similarly the air and track temperature, particularly for more extreme conditions (hotter or colder), were considered factors that could significantly influence running performance, and monitoring of this was identified as desirable by the participants.

Location, as monitored by a Global Positioning Device, (GPS) was identified as very useful information. Many of the participants clearly had some experience with training using existing GPS based systems, such as watches, and the benefits identified – particularly for longer distance. Furthermore, the obvious relationship between location and distance travelled was highlighted, but the difficulty of accounting for elevation within ‘distance’ was suggested as more difficult to measure by many participants.

Several participants identified elevation as an important characteristic that could influence training and running. These comments were normally based around altitude training and how that influences running performance; in particular the link between gradients and effect on heart rate was identified as an inter-dimensional relationship (see Figure 2).

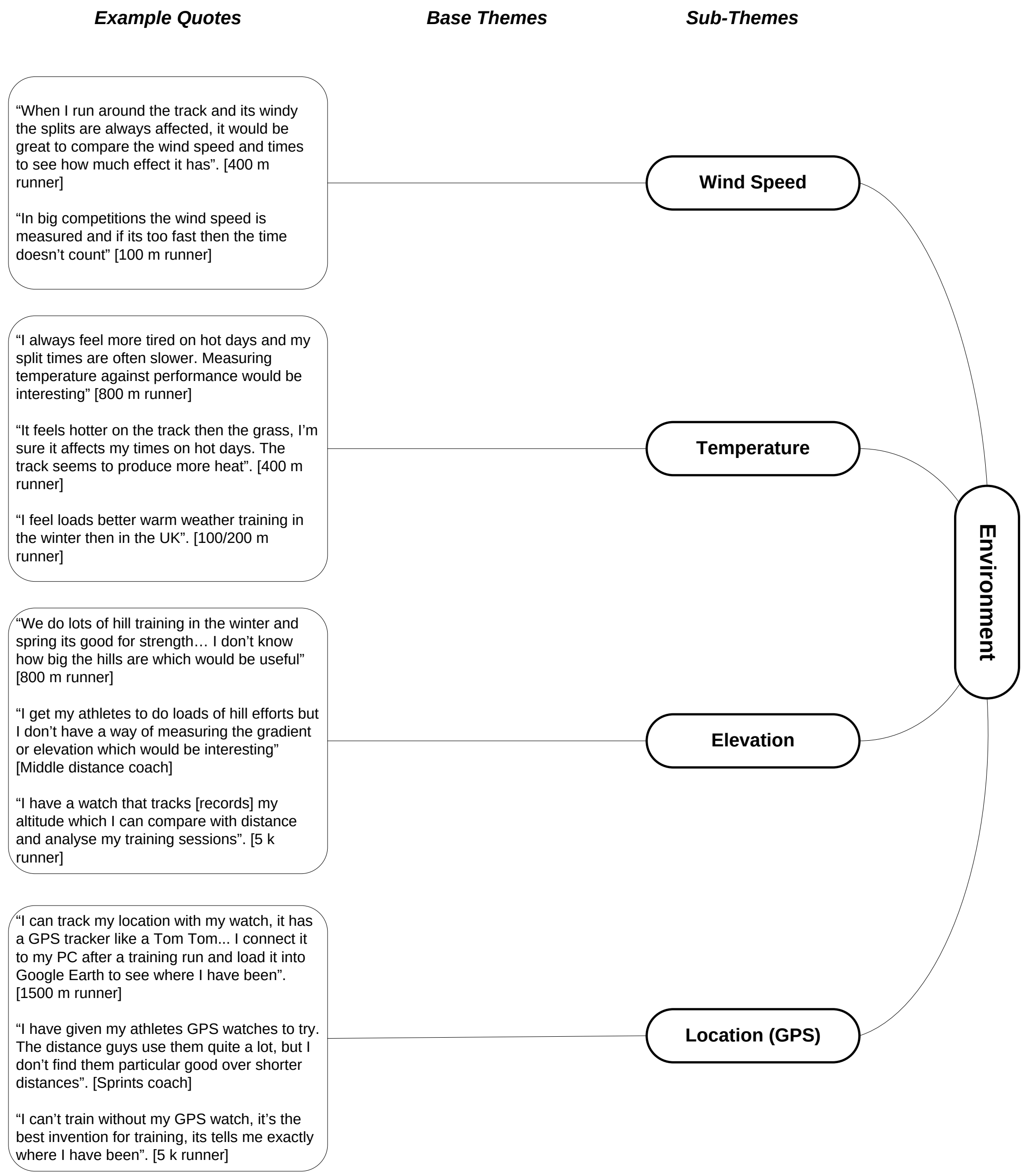


**Figure 5 – A tree diagram for the dimension 'environment'**

### *3.1.4 Performance*

The dimension 'performance' (see Figure 6) was the most commonly mentioned theme and was derived from five sub-themes. The most common and simple measurements in running training is a combination of distance and duration which is converted to speed and these three sub themes were often mentioned interchangeably by the participants. It appeared that speed was more dominant for the sprinters however, and time and/or distance were useful monitoring during a run or training by the distance runners.

Running duration is simply measured with a stopwatch. This device is very common and used by almost every athlete/coach as a training aid. More advanced devices that can indicate split times were mentioned as favourable and commonly used by coaches.

When running on a track distance is easy to estimate. However, several athletes identified that a way of measuring distance travelled accurately would be very useful for non-track training. Some athletes mentioned the use of GPS devices (e.g. Garmin ®), and/or accelerometer systems (e.g. Polar ®) counting strides, as a current technology for measuring distance. However, some athletes identified that the accuracy of these systems was, in their opinion, limited for short runs with variations in speed.

Running speed was the most commonly mentioned sub-theme by athletes and coaches. A method that is capable of measuring (directly or indirectly) running speed was seen as essential. The limitations of the currently available (indirect) devices over shorter distances were highlighted, but longer distance runners praised them.

Force generation and pressure distribution were identified by participants (predominantly coaches) as useful indicators of performance. Some of the comments by the participants related to both foot contact and performance hence the inter-dimensional relationships shown in Figure 2. Force generation was identified as a potentially useful way of assessing the mechanics of running. Furthermore, pressure distribution of foot contact was also identified by athletes and coaches as a useful method of assessing running technique.

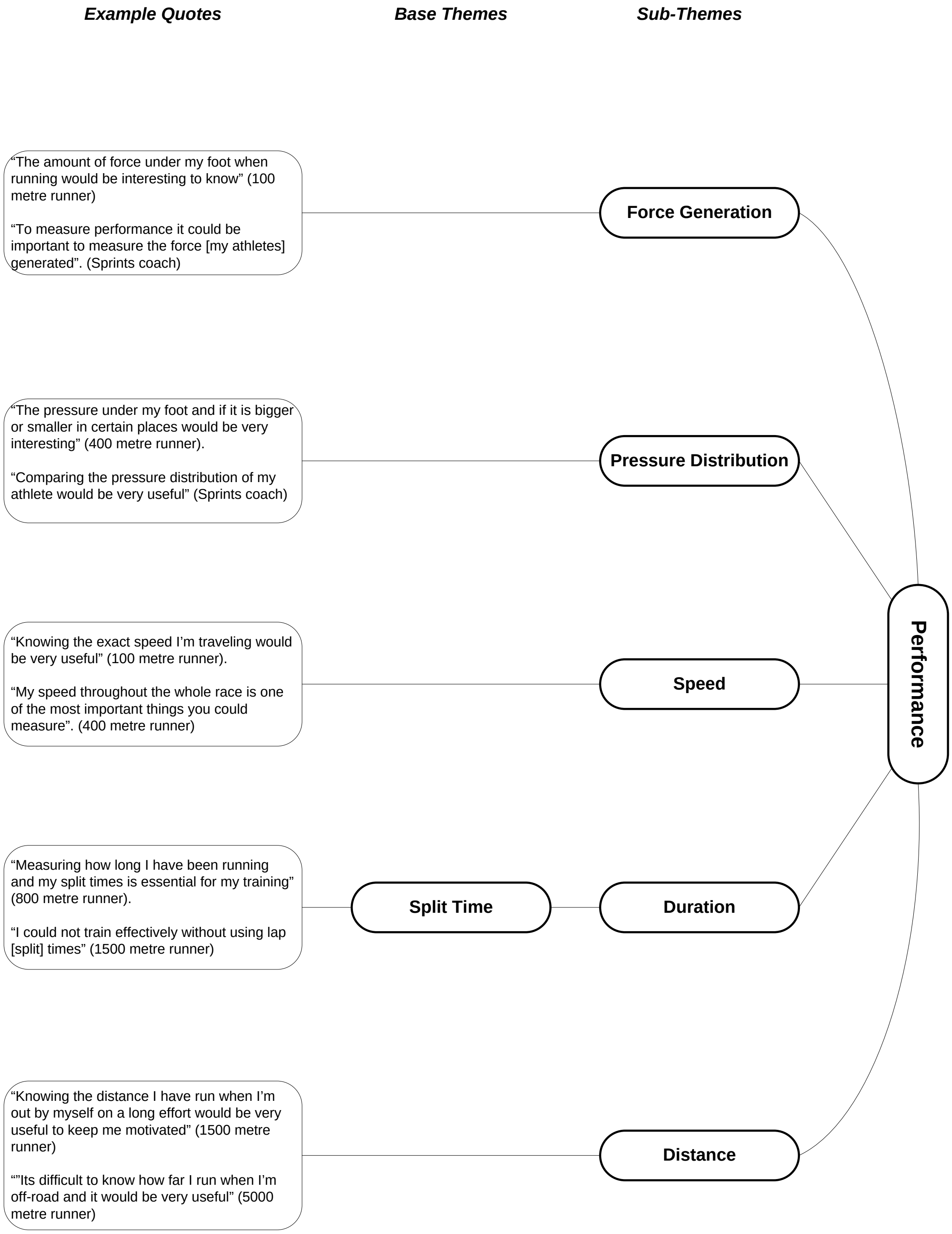


**Figure 6 – A tree diagram for the dimension 'performance'**

### 3.1.5 *Injury*

The dimension ‘injury’, see Figure 7, was formed from two base themes, prevention and rehabilitation. Some participants identified that a method of monitoring running style and performance that would facilitate feedback information during rehabilitation and also help injury prevention would be very useful. However, these respondents did not have any clear suggestions as to how this could be achieved nor suggested knowledge pertaining to the mechanisms of injury occurrence.

It was identified by the participants that fatigue can have an influence on their risk of injury. Hence the inter-dimensional relationship identified between the cardiovascular and injury dimensions (see Figure 2).

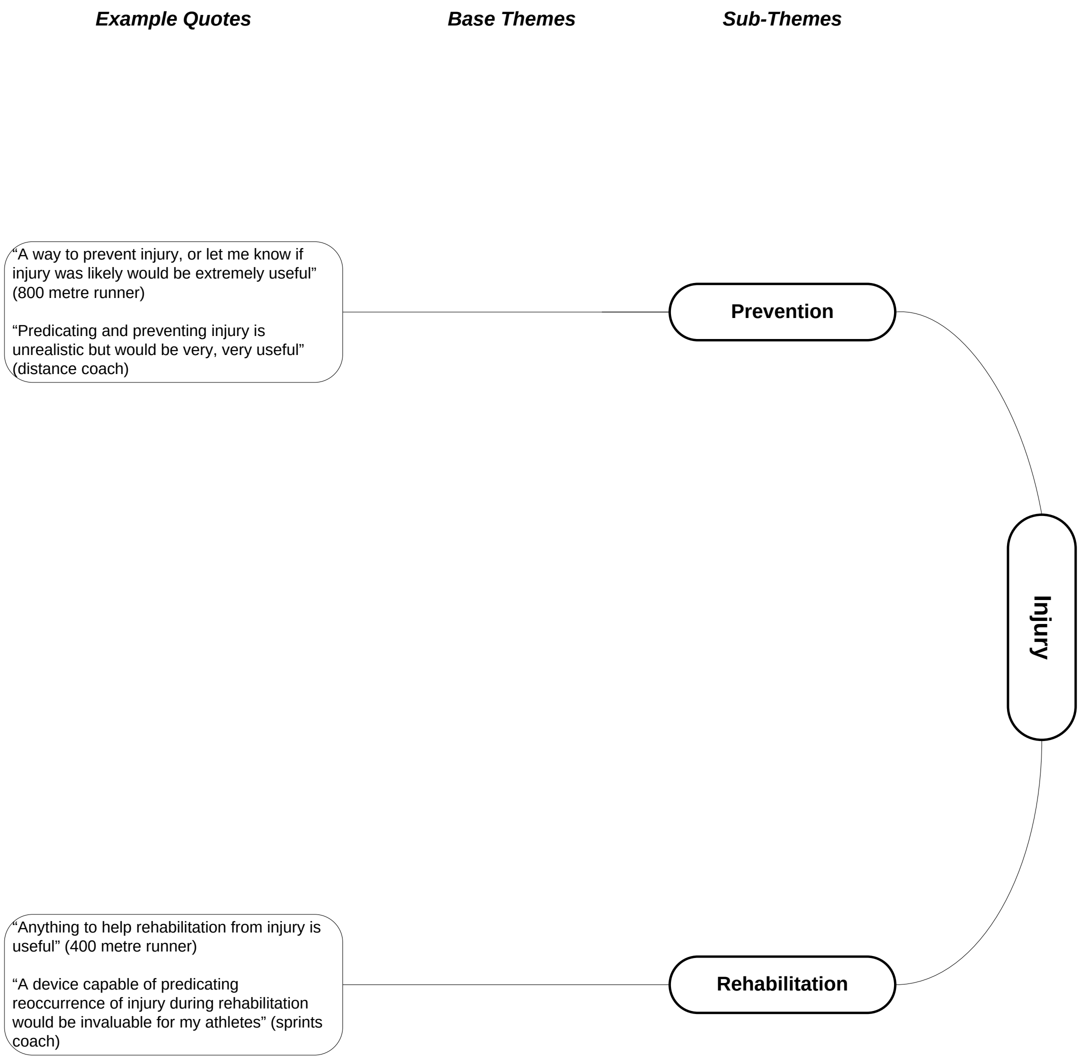


**Figure 7 – A tree diagram for the dimension ‘injury’**

### *3.1.6 Cardiovascular*

The dimension ‘cardiovascular’ (see Figure 8) was formed from three sub-themes: heart rate; breathing rate; and maximum utilisation of oxygen by the body during exercise, termed $VO_{2\ max}$. Participants identified the role that aspects of the sub-themes could have in helping to assess fatigue and how they could influence their risk of injury and speed performance. Heart rate can be measured simply by a monitor, commonly used by endurance athletes. Furthermore, some athletes identified a useful role of training to a specific heart rate (or range) rather than to a specified time or distance. More obtrusive to use are $VO_{2\ max}$ tests or breathing rate devices, but several participants mentioned the benefit of assessing their cardiovascular fitness using these methods in a laboratory environment.

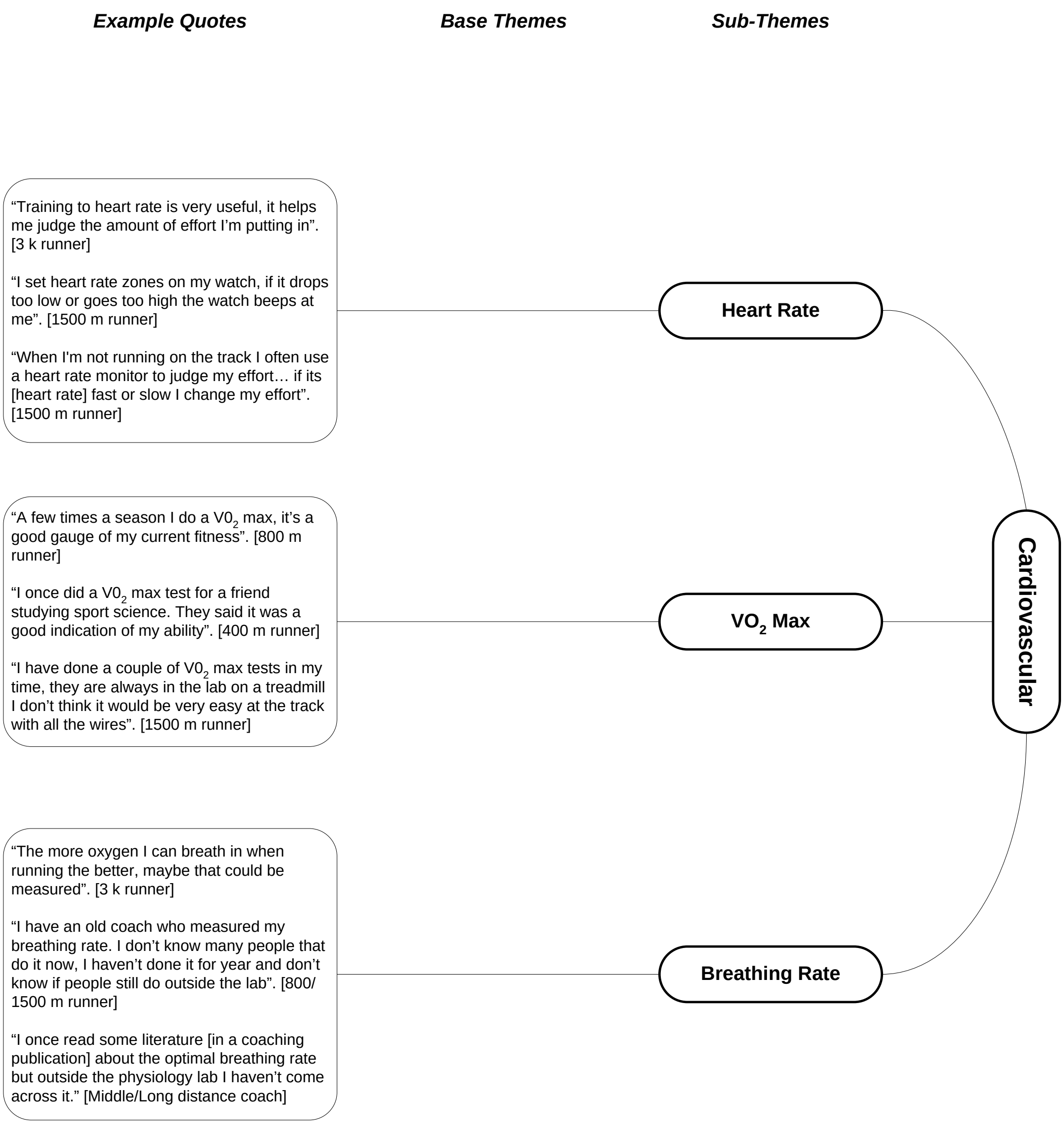


**Figure 8 – A tree diagram for the dimension 'cardiovascular'**

### *3.2 Quantitative Analysis of the Questionnaire*

A total of 73 questionnaires were returned from a total sample size of 151, a response rate of 48 %. Of the 73 returned questionnaires 62 were chosen for analysis, and from the 11 not used 6 were incomplete and 5 of the participants did not meet the minimum entry standard (i.e. their personal best performance was below the entry standard to the national competition, AAA for their age and gender) so were excluded.

The average age of respondent was 22.6 years with a range from 19 to 27 (excluding coaches). Although athletes often have more than one event at which they compete, the questionnaire specifically asked for their main event and personal best, and their feedback in relation to this. Some coaches stated that they had coached a number of athletes over a large range of events, and for this instance they were told to identify the events their athletes had performed at a higher standard, evaluated by national ranking, and provide feedback across these events only.

From the 62 questionnaires analysed, 51 were from athletes and 11 from coaches; made up of 26 females and 36 males; of which 28 were middle to long distance runners (800 metres upwards) and 34 were sprinters (100 to 400 metres). The number of athletes from each event (e.g. 100 metres) was too small to group by individual event, hence the grouping was done based on the categorisation of sprints and distance. Coaches responses were also analysed individually to determine any pattern of difference in response from their athletes. The questionnaires were assessed as a total and then compared in sub-set groups, comprising athlete versus coach, male versus female, and sprint versus distance.

### *3.2.1 Measurement Characteristics*

From the interviews conducted, 22 characteristics had been identified for further investigation via the questionnaire. These 22 characteristics were essentially the sub-themes and several base themes that emerged from the inductive analysis. Most are measurable properties or parameters. Figure 9 illustrates all 22 characteristics and the average score for each from the total group of respondents.

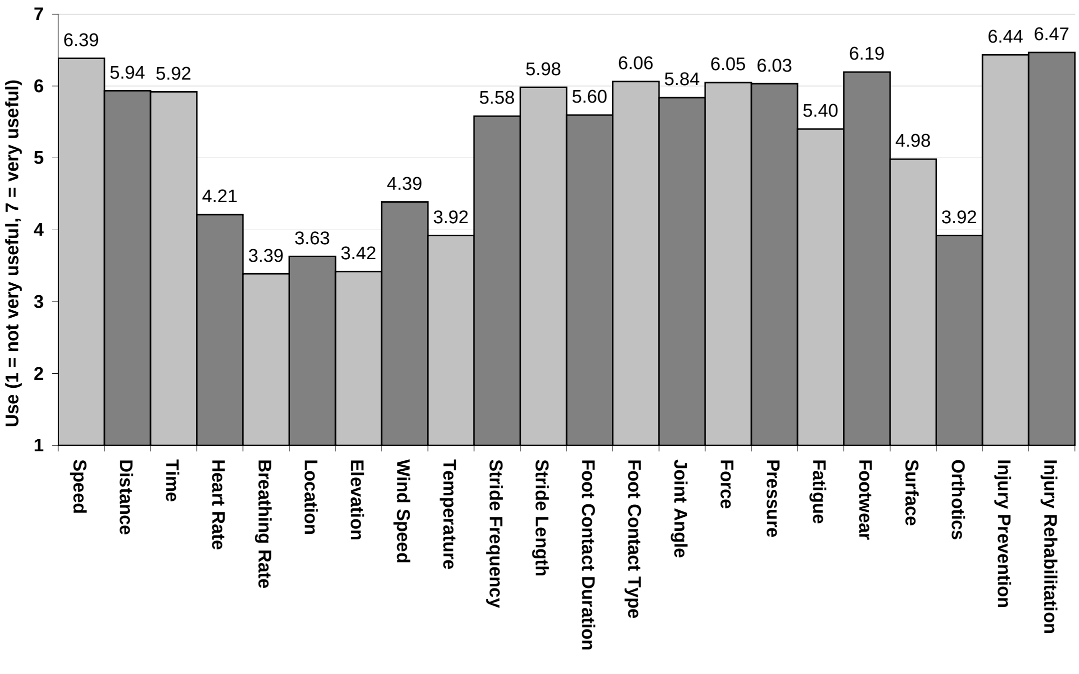


**Figure 9. The average rating from all 62 participants for 'usefulness' of the 22 characteristics.**

The most useful characteristics were identified as injury prevention and injury rehabilitation; closely followed by the measurement of speed, footwear, foot contact type, force and pressure. Stride length also scored highly. The characteristics identified as least useful were breathing rate and elevation, and perhaps surprisingly location also gave a relatively low score (<4). The most frequent differences in opinion, when analysing the subset groups, were between sprinters and distance runners, and Figure 10 illustrates the numerical difference for each characteristic between the average rating for the two groups. A positive difference relates to a greater preference for the sprinters and a negative difference illustrates a greater preference for the distance runners. The larger the numerical difference the larger the disparity between the group's views (The maximum difference possible is 7).

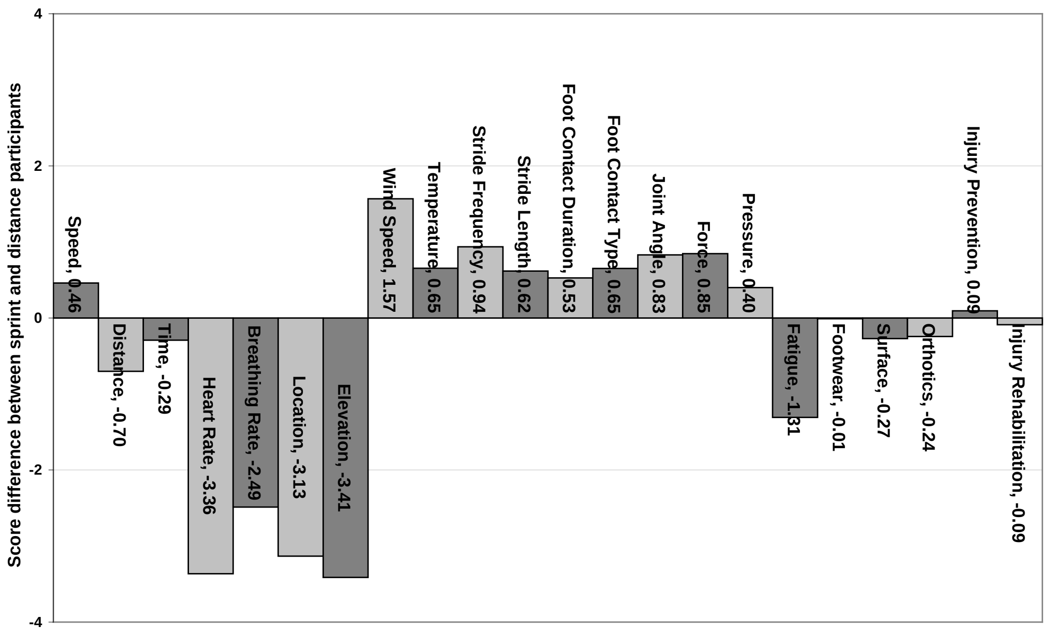


**Figure 10. A diagram representing the numerical difference between average rating score of the sprinters' group and distance runners' group**

Figure 10 shows the distance runners' group greatly prefer the characteristics relating to cardiovascular load (heart rate and breathing rate) and spatial position (location and elevation). Injury-related feedback, footwear, surface and time, distance and speed rated similarly between the groups. The sprinters' group, however, slightly favoured information regarding more detailed aspects of the biomechanics and kinetics of rapid propulsion, specifically the characteristics stride frequency, foot contact and forces and joint angles. Wind speed and temperature were also favoured by the sprinters, no doubt in light of the larger performance effect over shorter duration and distance than distance. The data also show that the characteristics of heart and breathing rate, location and elevation score between 0 and 1 for the sprinters' group alone and are considered 'not very useful'.

### *3.2.2 Participant Preferences for Measurement Devices and Experience*

When asked if they believed technology could help improve technique, 92 % of the 62 participants agreed that they thought it could. This is considered a positive result with regard to embracing technology specifically aimed at improve their training and performance. Furthermore, all respondents, but three, stated they would be willing to purchase a device with the capability of improving running technique. However, price considerations were not discussed.

They were asked about preferences for the physical and operational characteristics of a potential device including its size, weight, method/type of data presentation and recording frequency, again on a rating score of 1-7. This feedback was to help ensure any new device developed would consider the requirements of the end user as fully as possible, identifying the limits of acceptability. In order to help quantify their responses, without being specific about variables such as mass in grams or kilograms or size in centimetres etc., the simple descriptors ‘shoe weight’ and ‘shoe size’ were used. These descriptors were justified based upon the respondents’ terminology often used in the interviews to describe mass and size.

The scores for data presentation (5.79), device size (6.05) and data resolution (5.84) indicated high relative importance to the respondents. The preference for the timing of data collection and feedback was ‘real-time’ for the vast majority of respondents. The majority of participants favoured a device capable of providing user feedback ‘as fast as possible’ to provide effective management of decision making regarding performance.

The maximum weight of device the participants would be willing to wear gave a relatively large spread of opinions in the response. The most popular category was ‘1/2 typical shoe weight’ from 35 % of the responses, closely followed by the category ‘typical shoe weight’ with 32 %. The ‘twice typical shoe weight’ and ‘size required to achieve all the required functions’ was only selected by a total of 11 % of respondents. Weight was described to the athlete/coach as a basic running training shoe (typically a mass of 250 grams) rather than spike or racing shoe. Most athletes stated they were prepared to compromise on size for proven functionality improvements (55 %). However, 30 % preferred a device that was ‘light’ regardless of functionality. Further investigation of the results illustrated that the sprinting group were much less likely to accept a heavier device than distance runners.

Participants were also asked in the questionnaire about their experience of current technologies in providing feedback to them during training. All respondents stated they had some experience during training, varying from the simple stop watches (all respondents), through speed/distance monitors (including GPS) for 36 % of respondents, force platforms for 26 % of respondents, and the lowest experience of video analysis of motion (14 % of respondents). There was no clear relationship between experience and event type, or between either gender or coaches and athletes. There was a slight trend toward middle/long distance runners using more speed/distance monitors, however.

## 4. Discussion

The combination of interviews and questionnaires has allowed a detailed analysis of athletes’ and coaches’ opinions on preferences and requirements for measurement technology relating to running technique. The interviews made it possible for the participants to express in their own words what characteristics of running technique they felt were important to them, helping identify clustered themes that then facilitated the design of a targeted questionnaire, eliciting quantitative information on these 22 characteristics.

This section combines the qualitative and quantitative analysis and also includes relevant observations noted during the interviews, group discussions and questionnaire feedback.

During interviews there were several data quality issues of concern, including the participants misunderstanding what was being asked, the interviewer misinterpreting the responses and the preconceived attitudes and opinions of the interviewer influencing the participants' responses (Cohen and Manion, 1980). Throughout the interviews a number of methods were employed to reduce the potential for any bias or error. Prior to the interview phase, discussion with elite coaches and a performance analyst helped define athlete terminology and to construct the interview guide. The interviewer had been trained and had many years experience in interview techniques of this kind, and maintained clear and consistent questioning and probing using the interview guide.

For the interviews the analysis was initially grouped into three categories, one including the sprinters (100 to 400 m) one for middle and long distance runners (800 to 5,000 m) and one for the coaches. This was to reflect the potential differences between responses i.e. does a sprinter have the same requirements as a long distance runner? However, during the inductive analysis of the interviews the three groups were forming almost identical dimensions with differences mainly in frequency of response or emphasis. Consequently, analysis from all three groups was combined for the inductive analysis of the interviews. However, differences in opinion between sprinters, long distance runners and coaches (of different events) were identified in the questionnaire feedback (where greater subject numbers were used) and were consequently analysed separately.

There was clearly a large variation in technological awareness between the interviewees. Some were aware of the current technology, and advantages that could be obtained from their use, through direct experience or second-hand through colleagues, and articulated their responses well. However, some clearly had very little knowledge of current technology and what it could provide, hence their responses in this regard were limited and required prompting to explore their knowledge (of the 28 interviewees, 6 needed prompting). The interview guide was particularly important in this instance for ensuring a consistent approach was followed. The questionnaire feedback highlighted that, for this study, 57 of the 62 athletes were positive about the role technology could provide to help improve their technique. More than half had some experience of using technology to this end, and most stated they were willing to purchase and use a device *if* it could be shown to demonstrate a training advantage. Clearly this then is an issue for coaches and coach education, to ensure that some appropriate advice is given as to the specific benefits (and limitations of technology available). Unsurprisingly, the maximum size and weight of a device worn by the athlete produced a range of feedback, most wanting light and multifunctional devices with real-time feedback.

The 6 dimensions that emerged from the interviews can be further categorised into two distinct groups; direct measurements and indirect measurements. Direct measurements include ‘technique’, ‘performance’ and ‘cardiovascular’ and contain characteristics that are produced, controlled or caused by the athlete which can be measured directly. Indirect measurements include ‘footwear and surface’, ‘environment’ and ‘injury’ which comprise characteristics that can influence the athlete but are not directly measurable. However, the parameters are not mutually exclusive and base themes in one group can influence base themes in another. The sub-themes (and some base themes) of the 6 dimensions were further denoted as 22 characteristics of running technique and performance for subsequent analysis.

Many of these 22 characteristics that were identified can, to some extent, be measured with currently available devices. Some devices are used regularly in training and competition situations, such as stopwatches, heart rate monitors and speed/distance monitors. Technologies that are related to more advanced measurement and evaluation of the athlete biomechanical system are not uncommon it appears. However they are clearly restricted in the uptake of their use by influential factors such as availability, the ease of use and analysis (and the post measurement time required for analysis), and are in most cases limited to the laboratory environment.

In addition, it was clear from the analysis of respondent feedback that some technologies are used more by specific sub-groups of athletes than others. For example, heart rate monitors, speed distance monitors and GPS systems were commonly used by mid to long distance runners. A lack of accuracy (and resolution) at shorter distances was identified as an issue by sprinters.

Table 1 reviews common technologies currently available to athletes and coaches with comments on how the participants in this study currently use them, and includes notes on their strengths and weaknesses. The 22 characteristics identified in this study are shown where it is considered that they are addressed by the existing device or measurement technique.

## Table 1. Overview of Existing Devices and Comments on Suitability

| Device group | Primary Functions | Primary Use | Example Products available | Limitations | Usage rate [3] | Comments | Characteristics Measured (from the 22 identified) |
|---|---|---|---|---|---|---|---|
| Stopwatch[1] | Records the time taken to run a specific distance/effort. | Training competition | Most watch manufacturers | Accuracy, variable speed not measurable. | 100 % | Most commonly used training aid | Time (speed) |
| Heart Rate Monitor[1] | Records the heart rate during exercise | Training | Polar<br>Cardio sport | None | 64 % | Commonly used by distance runners | heart rate |
| Force Plate | Measures the reactive force of the athlete during running | Research | RSscan<br>Kistler | Portability, cost, analysis, user knowledge, time to analyse | 26 % | Limited to a laboratory environment | Foot contact force & duration, centre of pressure |
| Motion Capture / High Speed Camera | Measures motion at high speed, as a free field or with markers at specified locations on the athlete to record joint/limb motion | Research | Many specialist manufacturers, for motion analysis: Vicon, Codamotion | Market competition leading to improvements. Not routinely used, issues of expertise required, portability, cost. | 14 % | In general limited to a laboratory environment. Useful for posture, gait, biomechanical analysis | Stride length, stride frequency, joint angle (combined with force measurement forms a powerful tool for dynamics) |
| Pressure Sensors (mats/insoles) | Records the pressure distribution under the foot during running | Research | Pedar; Tekscan; Xsens; RSscan | Cost, analysis time, expertise required | 15 % | Limited to a laboratory environment | Foot contact type/duration, Foot pressure |
| GPS tracker[1] | Measures the GPS location of the athlete when running | Training | Garmin Forerunner<br>Polar | Low sample rate, not good indoors or under tree cover | 36 % [2] | Not ideal for sprinters due to low frequency sampling rate | distance, location, elevation, speed |
| Shoe Pod Accelerometers[1] | Attached to the foot, measures acceleration to interpret foot contact to count steps and estimate distance. | Training | Polar<br>Nike (iPod) | Accuracy, not very good when pace is changed regularly. Slow resolution | 36 % [2] | Good for long range running with standard cadence | Speed, distance |
| Wind Gauge, anemometer | Measures wind speed | Competition | Many manufacturers, hand-held devices | One direction | Elite competitions | Used mainly in Competitions | Wind speed |
| Thermometer | Measures temperature | Research | Many manufacturers | None | Unknown | | Temperature |
| Physiology Equipment | Measure the body's response to exercise | Research | Specialist manufacturers of healthcare products | Portability, time taken for analysis | Unknown but normally research and health testing | Occasional use in a laboratory environment | Heart rate, breathing rate, blood lactate, $V0_2$ max tests, Estimate fatigue |

Notes: [1]Many of these systems are often combined within another product (e.g. heart rate monitor with a stopwatch or GPS with a stopwatch and heart rate monitor). [2]Combined in the questionnaire

[3] Percentage of questionnaire respondents who indicated that they used the device or technique

From Table 1 it can be seen that nearly all of the 22 characteristics identified in this study can be measured (to an extent) with currently available technology. However, it is clear that many measurement techniques are not routinely available, nor routinely used – and the reasons for this have not been investigated but are considered to include cost, locality, knowledge and expertise of the coach (and athlete) and general support for these activities by the sport governing body/funding body. It may also be that whilst many of the more advanced techniques have been used at research level (Billing et al., 2006), there is still further work required to assess the accuracy and repeatability of measurements (Putti et al., 2007), and the way they record and present data compared to the requirements of the user. As a very simple example of poor accuracy the Nike pod (fitted to a user's shoe) is initially calibrated to the user's typical stride length during a single short run and then assumes that all running strides thereafter are the same length as the calibrated stride in further measurements and analysis. This can lead to large errors when running up or down hills in comparison to on the flat for example.

In regard to athletic performance, foot contact duration and foot contact type were ranked by the participants as highly useful characteristics to measure. In addition to stride length/frequency these characteristics are technical aspects of running that greatly influence performance (see Figure 1). Interestingly, coaches rated these 'foot-surface' characteristics more highly than the athletes, perhaps through a better understanding of the biomechanical and technical style factors for running performance. In addition, sprinters group identified the foot-surface characteristics with a higher ‘usefulness’ rating than the distance runners group.

The force generated under the foot when running is commonly measured via a force plate. These measurements provide ground reaction information feedback at almost real-time. Cost and placement options of the force platform make their widespread use outside of the laboratory unrealistic, but they are used in many sporting excellence centres such as indoor athletics and cricket bowling nets. Underfoot pressure can be assessed by current systems of pressure mats or, more recently with in-sole systems, and can provide almost real-time feedback of the pressure distribution under the foot. The mat systems are typically used in podiatrist and physiotherapy surgeries to analyse gait and foot loading for design of orthotics – at walking speed. The mat systems are restricted in data collection frequency. The in-sole systems are designed to be more useful for foot loading within the shoe and studies to date include design of boots and shoes, and athlete loading across the foot in more realistic in-game (or in-competition) scenarios. Whilst the in-sole technology is clearly advancing, and sample rate is around 500 Hz maximum, there are issues with repeatability and reproducibility and durability of the in-soles. Furthermore, quite advanced knowledge is required to utilise the equipment and analyse the results, and large volumes of data are collected over short time periods requiring significant post-measurement processing time dependant on the outcomes required. It would appear, however, that robust and user friendly portable measurement systems for feedback to athletes and coaches on the foot-surface interaction would be welcomed. In relation to this, De Cock *et al., (2006)* demonstrated that runners can be grouped according to their foot-surface contact patterns and suggested that these patterns are distinct between runners.

Whilst it is clear that technology can contribute to 'direct measurements of performance', less indirect factors such as injury prevention/rehabilitation – whilst highly desirable and understandably so - are clearly more complex to assess or measure. Injury occurrence can relate to a combination of several of the other characteristics, either as a trauma type injury (from excessive force, joint angle and so on) or from repeated actions that contribute to a chronic or overuse injury. The individual athlete's injury propensity, and past history of injuries, is also considered relevant to the 'risk' associated with their training and competition, with many other extrinsic factors. However, it is considered that for an individual athlete the development of a database of information relevant to their foot-surface contact behaviour would be advantageous. It has been postulated that a 'signature' of running technique may exist (Putti et al., 2007). The establishment of athlete benchmark data could then be particularly useful in identifying anomalies during specific periods of crucial training prior to competitions, or following any period of dip in form, illness or injury, and permit some evaluation of the anomaly. This clearly relies on building knowledge of typical or individual foot strike signatures in order to predict with any degree of accuracy or success the classification of anomalies and longer-term developing and link to the likelihood of injury (re)occurrence. This hypothesis is considered of merit for further investigation. However, it was also clear from this study that whilst the coaches and athletes indicated that a ‘device’ capable of measuring when injury could occur would be extremely useful they did not relate aspects of foot-surface force or pressure distribution to injuries, or suggest that they felt changes in their running style could contribute towards injury. This does not diminish the possibilities for such an approach, but demonstrates the important role of high quality scientific research that provides clearly communicable outcomes to show any benefits to the athletics community – who are according to this study ‘open’ to (appropriate) technology.

The size and weight of a device were raised in the questionnaires and mentioned in the interviews. The participants highlighted that in order for them to accept and use a device it would need to be small, unobtrusive and light. This is a vital consideration when developing a new device to ensure the end-user is comfortable and confident in its use. There may be a compromise between functionality and size, of course. In addition, data presented in real time was identified as very important to the users. Furthermore, although not investigated in the study it is clear that the *form* of data presentation is as important as the data measured – such that the coach or athlete could quickly be taught how to interpret or use the information relayed back to them. To this end, it is clear that whilst a system would require some flexibility in its range of functions and user settings – it must also be easily configured to suit the user and thereafter be capable of providing clear numeric or diagrammatic output. To permit long-term ongoing development of a database for individuals some form of download to a PC with software to manipulate the data and present it is also required.

These outcomes suggest, in brief, that a device capable of being unobtrusively worn by the athlete, and which can record aspects of foot-surface contact – in sufficient detail to capture personal attributes – and other related performance metrics (such as heart rate) simultaneously or in a synchronised way – would be beneficial to training to improve performance and also rehabilitation from injury.

## 5. Conclusions and Recommendations

This study elicited the feedback from 79 athletes and 15 coaches on their opinions relating to measurement of running performance, via interviews (32) and follow up questionnaires (62).

The study identified 22 characteristics important to the coach and athlete, from inductive analysis of the interviews. The questionnaire further quantified the relative usefulness of these 22 characteristics – and showed useful trends between two running sub-groups, sprinters and middle-long distance.

The respondent feedback analysis and discussion has highlighted several key outcomes, which provides a platform for directing future research and technology development for routine measurement of aspects of running performance.

A brief overview of existing measurement devices has identified that the requirements of the athlete and coach can mostly be fulfilled by a series of measurements with technology currently available – but not concurrently.

However, in many cases the specific characteristic considered to be restricted by availability and associated expertise for routine use, and is also mainly located in laboratories.

There is, however, a desire and apparent willingness from athletes and coaches to utilise measurement of a range of technical aspects of running technique, with useful suggestions as to the appropriate form of device(s) they would welcome.

The development of a routine and portable device to integrate measurement of many aspects of foot-surface contact is considered to be of great benefit, for training and improving technique and performance through to injury rehabilitation.

However, it is recommended that future research work aimed at developing new equipment follow a pragmatic approach, comprising:

- carry out detailed trials with a small subject group (athletes and coaches) of key current technologies, formulating opinions regarding ease of use, portability, ideal form of data display and long-term aspects of delivering a database of information regarding their athletic performance.
    - within the above pilot study, further establish if the running signature is unique between individual athletes.
- partner a leading device manufacturer to research and develop a multi-tasking portable measurement device.

- trial the equipment at pilot scale, and refine it for mass marketing.
- ensure the relevant coach and athlete support/funding groups (i.e. UK Sport, EIS, UKA) participate in latter validation trials and have appropriate information to disseminate to their members to permit objective decision making on whether and when to use the new technology.

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## 7. References


Billing, D. C., Nagarajah, C. R., Hayes, J. P., Baker J. (2006). Predicting ground reaction forces in running using micro-sensors and neural networks. Sports Engineering, Vol. 9, 15-27, ISEA.

Cohen, L. and Manion, L. (1980). Research Methods in Education. London: Routledge.

De Cock, A., de Clercq, D., Willems, T. and Witrouvuw, E. (2005) Temporal characteristics of foot roll-over during barefoot jogging: reference data for young adults. Gait and Posture 21, 432-439, Elsevier.

De Cock, A., Willems, T., Witrouvuw, E., Varenterghem, J. and de Clercq, D. (2006) A functional foot type classification with cluster analysis based on plantar pressure distribution during jogging. Gait and Posture 23, 339- 347, Elsevier.

De Cock, A., Willems, T., Witrouvuw, E., Varenterghem, J. and de Clercq, D. (2008) The trajectory of the centre of pressure during barefoot running as a potential measure for foot function. Gait and Posture 27, 669- 675, Elsevier.

Dixon, S.J. (2006). Application of centre of pressure data to indicate rearfoot inversion-eversion in shod running. Journal of the American Podiatric Medical Association, 96, 305-312.

Fleming, P. R., Young, C., Dixon, N., Roberts, J. R & Jones, R. (2005). Human Perceptions of Artificial Surfaces for Field Hockey, Sports Engineering, Vol. 8, No. 3, pp121-136, 2005, ISEA

Hay J.G. and Reid J.G. (1988) Anatomy, Mechanics, and Human Motion (2nd edition) Englewood Cliffs, NJ: Prentice Hall.

Heller, B., Haake, S., J., Kirtley, C. (2004). An instrumented insole for measurement of foot motion. In The Engineering of Sport 5: Proceedings of the 5th International Conference on the Engineering of Sport (edited by M. Hubbard), Vol. 2, pp. 201 - 206. ISEA, Sheffield UK. ISBN 0-9547861-2-2.

Hocknell, A., Jones, R. and Rothberg, S.J. (1996). Engineering ‘feel’ in the design of golf clubs. In The Engineering of Sport: Proceedings of the 1st International Conference on the Engineering of Sport (edited by S.J. Haake), pp. 333 - 337. Rotterdam: A.A. Balkema.

Patton, M.Q. (1990). Qualitative Evaluation and Research Methods. London: Sage.

Putti, A.B., Arnold, G.P., Cochrane, L. and Abboud, R.J. (2007). The Pedar in-shoe system: Repeatability and normal pressure values. Gait & Posture, Volume 25, Issue 3, Pages 401-405, Elsevier

Roberts. J. R, Jones. R, Harwood. C, Mitchell. S & Rothberg, S (2001) Human perceptions of sports equipment under playing conditions. Journal of Sports Science 19 pp 485-497.

Scanlan, T.K., Ravizza, K. and Stein, G.L. (1989a). An in depth study of former elite Figure skaters: I. Introduction to the project. Journal of Sport and Exercise Psychology, 11, 54-64.

Scanlan, T.K., Stein, G.L. and Ravizza, K. (1989b). An in depth study of former elite Figure skaters: II. Sources of enjoyment. Journal of Sport and Exercise Psychology, 11, 65-83.