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BIOMECHANICS

Biomechanical and Psychological Analysis of High School, Intercollegiate, and Elite Long-Distance Runners

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Abstract

It is undeniable that efficiency and mentality are crucial to achieving optimal athletic performance during competition. However, development of psychological skills is often neglected, particularly in lower levels of competition. The purpose of this study was to analyze and compare the biomechanical efficiency and psychological skills use among high school, intercollegiate, and elite long-distance runners. Data were gathered from six individuals, one male and one female for each of the three assessed levels of competition. Biomechanics is a discipline that, when applied to sports, functions as a method of identifying "ideal" joint positions and movements that allow athletes to obtain optimal efficiency. Mean deviations from the ideal values during the stance phase were 9.8° for high school, 11.35° for intercollegiate, and 5.85° for elite. Mean scores of the Athletic Coping Skills Inventory Questionnaire-28 were 51 for high school, 50 for intercollegiate, and 63.5 for elite. Mean scores of the Sports Imagery Questionnaire were 76.5 for high school, 78.5 for intercollegiate, and 90.5 for elite. In this study, elite athletes outperformed high school and intercollegiate athletes in efficiency and

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psychological strengths; however, few differences were observed between high school and intercollegiate athletes. Additionally, discrepancies in psychological skills appeared to be more prominent than differences in efficiency. This difference could result from efficiency being emphasized even in lower levels of competition. On the other hand, psychological skills training is completely ignored, or inadequate if employed, in lower levels of competition. For this sample, individuals in lower levels of competition lacked the psychological skills acquisition that was present in elite runners.

Cross-country running is a growing sport that is becoming increasingly competitive. In 2009, Snyder, Earl, O'Connor, and Ebersole stated that the United States is home to approximately 30 million individuals who choose to participate in running, with 10 million individuals running periodically. Nicola and Jewison (2012) stated that because running closely resembles walking, it is a common misconception that running is considerably instinctual. However, various mechanical techniques exist that can greatly help performance, or hinder it if not properly executed. Norris (1998) identified two major phases that constitute the running cycle: the stance phase and the swing phase. The stance phase includes any time the foot and ground are in contact and can be further divided into three subphases: contact, mid-stance, and propulsion (Norris, 1998). The contact phase begins when the heel touches the surface, the mid-stance comprises the body weight shifting forward and results in flattening of the foot, and propulsion results when the toes push off the surface (Novacheck, 1998). Nicola and Jewison stated that when one foot is involved in the stance phase, the other foot should move in opposition and should be undergoing the swing phase. However, running requires that an athlete be in the stance phase less than 50% of the time, thereby creating an additional phase, called the float phase, during which both feet lose contact with the ground (Nicola & Jewison, 2012). The swing phase consists of an acceleration position in which maximum knee flexion, and therefore maximum knee acceleration, is reached (Broer & Zernicke, 1979).

Ideal joint positions have been identified for the phases of the running cycle. These ideal joint positions function to establish the positions and movements that allow for maximum efficiency and prevent injury. According to Broer and Zernicke (1979), when the foot is approaching the ground, ideally the ankle joint should be close to its neutral 90° position, the hip should be flexed about 30°, and the knee should be flexed about 20°. During initial contact, the knee is flexed to approximately 25° (Dicharry, 2010). During the mid-stance phase, the knee should then obtain a flexion of approximately 45° for shock absorption to occur effectively (Dicharry, 2010). When the foot is preparing for propulsion, knee extension should then approximate 25° (Novacheck, 1998). The beginning of the swing phase will then follow, and maximum knee flexion should occur at approximately 90° (Novacheck, 1998). Broer and Zernicke specified that the late swing phase should involve the regress of the joint movements back to the ideal positions identified for the initiation of the stance phase. Besides the importance of proper joint positions during the stance phase, Broer and Zernicke emphasized the importance of increased knee flexion during the acceleration position of the swing phase. Enhanced knee flexion, in turn, increases knee acceleration, allowing for greater knee extension (Broer & Zernicke, 1979). This greater knee extension will then allow the individuals to have a greater propulsion force when pushing off from the stance phase, suggesting greater efficiency (Broer & Zernicke, 1979).

In addition to biomechanical efficiency, psychological factors play a critical role in athletic performance. In 2011, Weinberg and Gould suggested that in competition with an opponent of matched abilities, the outcome of the competition is caused by roughly 50% mentality. In some sport skills, mentality can account for as much as 80%–90% of the outcome (Weinberg & Gould, 2011). In particular, mental toughness has been recognized as a noteworthy attribute that helps athletes prevail (Bull, Shambrook, James, & Brooks, 2005). It has been suggested that mental toughness is the determinant factor of success between two athletes of equal physical, technical, and tactical skills (Gucciardi, Gordon, & Dimmock, 2008). Additionally, Slack, Butt, Maynard, and Olusoga (2014) stated that mental toughness is necessary for elite success and for the success of high-achieving athletes. However, numerous definitions of mental toughness exist, making it difficult to grasp fully the idea of what it means for an athlete to be “mentally tough” (Slack et al., 2014). For example, Dennis (1981) implied that mental toughness pertains to an athlete's ability to cope with and overcome failures. On the other hand, Loehr (1995) suggested that mental toughness refers to the superior psychological abilities of an athlete in comparison to others. Still, others, such as Werner and Gottheil (1966), have suggested that mental toughness is simply a personality trait, whereas others, such as Gibson (1998), have suggested that it is a state of mind that can be acquired and is not inherent. In 2008, Gucciardi, Gordon, and James defined mental toughness as "a collection of values, attitudes, behaviors, and emotions that enable you to persevere and overcome any obstacle, adversity, or pressure experienced, but also to maintain concentration and motivation when things are going well to consistently achieve your goals" (p. 278). This definition was meant to incorporate various previous definitions of mental toughness and demonstrate that mental toughness includes various human characteristics and an individual's ability to persist in the face of adversity as well as to maintain concentration even when no challenges are being faced (Gucciardi, Gordon, & James, 2008).

Behncke (2004) also claimed that the inability of athletes to control their psychological state during a competition greatly inhibits their self-confidence, well-being, and future performance. However, the development of psychological skills is often neglected, particularly in lower levels of competition (Weinberg & Gould, 2011). For example, in a study conducted on high school coaches, only 13% recognized that a certification existed from the Association for Applied Sport Psychology (AASP) that was designed to help coaches incorporate sport psychology into training effectively (Zakrajsek, Martin, & Zizzi, 2011). In the study, 3% of high school coaches had used psychological skills training and 62% had no intentions to integrate psychological skills training and physical training. At the intercollegiate level, psychological skills training has begun to be more accepted; however, few coaches integrate psychological skills training with physical training (Zakrajsek, Steinfeldt, Bodey, Martin, & Zizzi, 2013). On the other hand, in a study conducted by Sullivan and Hodge (1991), coaches of elite athletes rated psychological skills as being very important for training purposes and for athlete success. Of the elite coaches, 95.6% incorporated psychological skills training into practices, spending an average of 2.25 hr a week on psychological training (Sullivan & Hodge, 1991). These studies demonstrate the inconsistency in psychological skills training at high school, intercollegiate, and elite levels.

Behncke (2004) stated that greater motivation must exist for psychological skill acquisition than for physical training. This effect likely stems from the observable results of physical training, thereby making it easier for individuals to become engaged and remain motivated (Behncke, 2004). With the importance of psychological skills and the demanding levels of motivation necessary to obtain proper psychological skills training, coaches need to promote athlete engagement in psychological skills development. Gucciardi, Gordon, Dimmock, and Mallett (2009) provided evidence that coaches play a pivotal role in the athlete's psychological skill acquisition, finding that besides families, coaches are the most influential in athlete advancement of mental toughness. Martin, Lavallee, Kellmann, and Page (2004) found that athletes who had visited a sport psychology practitioner at least once were more inclined to appreciate advantages associated with the use of psychological skills and were less hesitant to seek future psychological consultations. It has been identified that coaches who attend a USA certification clinic are more prone to believe that psychological states can be modified with proper teachings, thereby demonstrating that coach participation in psychological skills training workshops encourages coaches to integrate psychological and physical practice (Gould, Hodge, Peterson, & Petlichkoff, 1987). Coaches' appreciation for the importance of psychological skills development can then alter athletes' perspectives and can encourage athletes to adopt psychological skills training (Martin et al., 2004). Even though mentality accounts for daily fluctuations, and even though the significance of mentality for sports success is now emphasized, little sport psychology training is incorporated into practice (Weinberg & Gould, 2011). Instead, athletes primarily focus on physical training, spending between 10 and 20 hr a week on physical practice and devoting little time to mental training development (Weinberg & Gould, 2011).

The purpose of this study was to analyze and compare biomechanical efficiency and psychological skills use among high school, intercollegiate, and elite long-distance runners. Data were gathered from six individuals, one male and one female for each level of competition observed. This was done to determine if trends exist in either biomechanical efficiency or psychological skills at different levels of competition. In turn, I believe that this study will provide insight about the factors that seem most important in allowing individuals to advance into a higher level of competition adequately.

Method

Participants

The participants in this laboratory experiment included six cross-country runners between ages 17 and 40. Distinguished athletes were recruited from a small high school, a Division III college, and an elite runner track club, all located in California. Assessment was conducted on the biomechanics and the psychological skills of individuals in three competition levels: high school, intercollegiate, and elite. One male and one female were recruited for each level.

Materials

The materials needed for the biomechanical analysis included a video camera, white athletic tape, a tripod, a cassette, a measuring tape, a reference object, and the Dartfish software program. For the psychological skills data collection, the Athletic Coping Skills Inventory-28 (ACSI-28; Smith, Schutz, Smoll, & Ptacek, 1995), the Sports Imagery Questionnaire (SIQ; Hall, Rodgers, & Barr, 1990), and a writing utensil were used. The ACSI-28 is a generalized questionnaire comprising seven subscales. These subscales include coping with adversity, coachability, concentration, confidence and achievement motivation, goal setting and mental preparation, peaking under pressure, and freedom from worry. The SIQ is specific to imagery and evaluates an individual's ability to visualize scenarios and the vividness of those scenarios. Specifically, the vividness of the scenarios is assessed using ability to hear and see the surroundings, feel the movements, feel the emotions, and control the image.

Procedures

The goal of this experiment was to perform a qualitative and quantitative analysis that would allow for the comparison of biomechanical efficiency and psychological skills usage among high school, intercollegiate, and elite cross-country runners. Participants were filmed to identify their biomechanical efficiency. The high school and elite participants were filmed on the same day, in the late morning, and on the same track. The intercollegiate athletes were filmed 2 weeks later, roughly at similar times, but on a different track. A tripod was used to ensure video quality by stabilizing the camera. The tripod was adjusted by lengthening and shortening the tripod legs. To ensure that athletes' joints were clearly visible during video examination, athletes were asked to wear tight-fitting clothing and to place a strip of white athletic tape on joints to be analyzed. The joints that were taped and scrutinized included the shoulder, the elbow, the wrist, the hip, the knee, and the ankle. The camera lighting was adjusted because a dark video would result in difficulty of joint distinction. Additionally, it was made certain that the camera did not face the sun as this would similarly cause difficulty in identifying joint positions, possibly compromising data validity. It was made certain that the camera was level in the anterior and posterior directions and the side-to-side direction. Also, because segment length and joint measurements were crucial, the camera was held perpendicular to the plane of motion of the athlete to ensure accurate readings. The camera was placed at the farthest distance possible that allowed for the formation of a large image of the individual being filmed and for all body segments to be fully visible. The zoom button was used to increase the size of the image. Ideally, the goal was to have only a small amount of unused image space in the video. The reference object, a cone, was selected and measured. This reference object was placed within the scope of the camera, at a location equidistant from that of the individual to the camera. The measurement of the cone was recorded, and its presence in the video allowed for the conversion of the pixel units on the video to "real-life" units.

Once the videotaping began, the zoom or focus on the camera was no longer adjusted. For this reason, the necessary equipment was properly adjusted before videotaping began. Before individuals were recorded, the camera was allowed to record for 1 min. Five running trials were recorded for each individual. The camera was no longer paused once an individual's trials began; however, 30 s were allotted between trials. After the completion of the final trial, the camera continued to record for another minute before the successive individual was recorded. Allowing the camera to record before, in between, and after trials was a way to guarantee that trials were not recorded over and that the full duration of the trials was recorded. After the videotaping, individuals were asked to identify the trial that felt most comfortable and natural. That trial was then used for future analysis and was uploaded to the Dartfish software program. The characteristic phases of the running cycle were identified and used for analysis, as depicted in Figure 1.

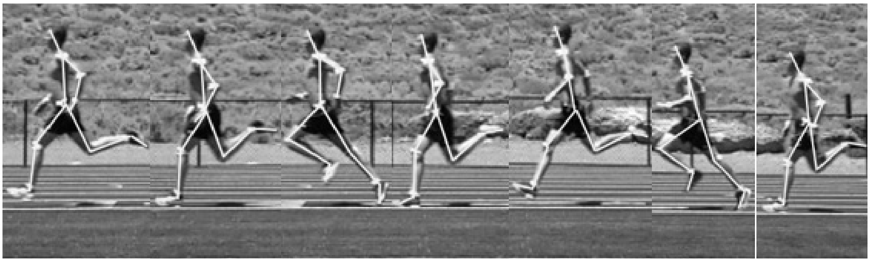

Figure 1. Phase identification of the running cycle.

Data of psychological skills were obtained through the application of two questionnaires: the ACSI-28 and the SIQ. The questionnaires were administered to the individuals prior to filming. Participants were informed that their answers were strictly confidential and that their names would not appear in the data. Participants were asked to answer questions as honestly as possible. The questionnaires were collected and later scored using the corresponding scoring sheet.

Statistical Analysis

The Dartfish software program permitted identification of each individual's joint position and joint degree of movement at various instances of the running cycle. Additionally, joint displacement, joint velocity, and joint acceleration data were acquired. Questionnaire results aided in the classification of mental resilience and coping abilities of the participants. Because of the nature of the small sample size, statistical significance could not be established; instead, trends in data were analyzed.

Results

Biomechanical efficiency data included participant joint position comparisons to ideal joint positions during the stance phase. Results were obtained by subtracting observed joint position from the ideal joint position, signifying total deviation from the ideal values. Table 1 demonstrates the degree of error in the three angles observed during the stance phase, with positive numbers representing excessive extension and negative numbers representing excessive flexion. The absolute errors of the joints analyzed were then added and divided by 3 to derive an average absolute error for each individual. The average in each group was then identified by adding the male and female score and dividing by 2. This average absolute error, demonstrated in Table 2, clearly delineated differences and permitted quick comparisons among groups. There was an error of 9.8°, 11.35°, and 5.85° in high school, intercollegiate, and elite runners, respectively. In addition to joint positions, the knee acceleration position was also analyzed and compared among the groups. The high school group displayed an average knee acceleration of 31.79 m/s^2, the intercollegiate group had an average knee acceleration of 31.89 m/s^2, and the elite group had an average acceleration of 25.66 m/s^2.

Table 1

Deviations From Ideal Joint Positions during the Stance Phase

Joint	Ideal values	High school		Intercollegiate		Elite	
		Female	Male	Female	Male	Female	Male
Ankle	90.0	7.2	7.0	15.2	5.0	1.2	6.0
Hip	150.0	−15.4	−6.2	−12.9	−6.6	−6.8	−8.4
Knee	160.0	−19.4	−3.7	−16.9	−11.4	−3.6	−8.9
Absolute Error		14.0	5.6	15.0	7.7	3.9	7.8

Table 2

Comparison of Averages Among the Three Groups

Methods of comparison	High school	Intercollegiate	Elite
Biomechanical deviation	9.8	11.4	5.9
Knee acceleration	31.8	31.9	25.7
ACSI-28	51.0	50.0	63.5
SIQ	76.5	78.5	90.5

In addition to biomechanical data, psychological skills data were collected through the use of questionnaires. Psychological data included the identification of an average total score on the ACSI-28 and the SIQ. High school and intercollegiate groups had similar scores with an average of 51 and 50, respectively. On the other hand, the elite group had a considerably higher score of 63.5. Similarly, the average SIQ scores suggested that high school (score = 76.5) and intercollegiate groups (score = 78.5) had similar visualization abilities, whereas the elite group (score = 90.5) had notably higher visualization abilities. The ACSI-28 was also used to determine the subscales for which the participants expressed the greatest mastery. I collectively analyzed the various groups in an effort to determine the psychological skills for which the participants displayed the greatest proficiency and the greatest deficiencies. The order of scores from highest to lowest was coachability, concentration, confidence and achievement motivation, goal setting and mental preparation, coping with adversity, and freedom from worry.

Discussion

The high school and intercollegiate groups proved comparable in biomechanical efficiency and psychological skills, whereas the elite group surpassed the high school and intercollegiate in biomechanical efficiency and psychological skills. The average absolute error during the stance phase suggests that joint positions of elite athletes most closely resemble ideal joint positions known to result in the greatest mechanical advantage. The intercollegiate group had a slightly greater absolute error than the high school group. A possible explanation for this is that intercollegiate athletes were members of an NCAA Division III school. Even though the intercollegiate athletes analyzed were superior among their division, the measurements may not have represented the highest level of intercollegiate long-distance runners, therefore explaining the resemblance to high school–level data. Another explanation is that previous injuries were not considered. If an individual had suffered from an injury, the injury could have resulted in greater joint position deviations from ideal values. Preexisting injuries could have skewed the data because of an incomplete recovery or an inability to revert to proper mechanics from lingering side effects.

Contrary to what was expected, the high school and intercollegiate groups had similar average knee accelerations, whereas the elite group had a lower average knee acceleration. Broer and Zernicke

(1979) found that greater knee acceleration is an indicator of greater biomechanical efficiency in long-distance runners, possibly indicating that, at least for certain aspects of running, the high school and intercollegiate groups exhibited greater efficiency. However, a possible explanation for this unexpected finding is that certain specifications of the foot, such as toe-off, mid-stance, and propulsion, were selected to confirm the analysis of a full cycle. However, no measures were taken to guarantee that peak knee flexion was analyzed. Therefore, no certainty existed that peak knee flexion, and therefore the greatest knee acceleration, was analyzed. Instead, the observed acceleration could have been a distinct point of the running phase at which the individual was undergoing knee flexion, but had not yet reached peak knee flexion. Additionally, athletes were asked to run at their usual 10K pace; however, this pace was different for each individual, leading to differences in knee accelerations.

Last, the results of both questionnaires suggested that the high school and intercollegiate groups had similar psychological skills ability, whereas the elite group had considerably higher psychological skills aptitude. It was not surprising to find a greater proficiency in psychological skills in elite runners compared to runners in lower levels of competition. However, it was unexpected to find few differences between high school and intercollegiate athletes. A plausible explanation for this trend is that the resources and the dedication necessary for proper psychological skills acquisition are not obtained until the elite level is reached. Another explanation is that because the intercollegiate athletes were from a Division III school, the proper resources were not available for psychological skills training and attainment. This study demonstrates the pivotal role that coaches play in psychological skills adoption and integration. The participants collectively scored the highest on the coachability subscale. This suggests that these athletes tend to have agreeable relationships with coaches. Therefore, if coaches emphasize and understand the importance of psychological skills training, athletes will be more likely to adopt a similar state of mind and more inclined to enhance their use of psychological skills.

Future Directions

Although distinct trends were observed in this study, future studies should include a greater number of participants. A greater number of participants would allow researchers to determine if the differences among groups are statistically significant. Additionally, the relationship between level of competition and the use of psychological skills cannot easily be determined from this experiment. For example, it is not known if greater use of psychological skills allows runners to advance to higher levels of competition due to greater mental toughness and resiliency. In contrast, placement in a higher competition could lead to a greater focus on psychological skill acquisition, leading to increased availability of resources that are necessary for developing psychological skills. Further studies need to be conducted to better understand the nature of this relationship. Last, physiology was not considered for this study. Runners in this study demonstrated greater discrepancies in psychological skills acquisition compared to biomechanical differences, but physiological differences are a crucial aspect of running. Integration of biomechanical efficiency, psychological state of mind, and physiology will result in a more complete study, allowing for a deeper understanding of the factors, if any, that become more important as athletes progress through increasing levels of competition.

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