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RESEARCH ARTICLE

EFFECTS OF DIFFERENT ARM KINEMATICS ON PERFORMANCE IN LONG DISTANCE RUNNING

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ABSTRACT

Arm action should be efficient as it generates various components of running mechanics. While many authors recommend that the arms should be moved with elbows held at about 90 degrees, some distance running athletes have used different arms movements with varying degree of success and failure during competitions. The study investigated how different arm kinematics affected cardio-respiratory parameters and stride patterns during the steady phase of long distance running. Mean values of working heart rate (WHR), estimated percentage of maximum oxygen consumption ($\%VO_2$ max), ventilation rate (VR), and rating of perceived exertion (RPE) were used to estimate energy cost of running with different arm actions. Ten elite Kenyan distance running athletes were tested in ten submaximal treadmill trial runs, each trial performed with different arm action for 15 minutes at a speed corresponding to individual's 80% running effort. Repeated Measures ANOVA indicated significant difference in WHR, $\%VO_2$ max, RPE, and stride rate (SR) at $p < .05$. Medium effect size was observed; Omega Squared (ω^2) = .20. Arm action consisting of about ±20 degrees oscillation of the hands around 90 degrees angle at the elbow is more efficient than running with arms held at 90 degrees angle at the elbows.

INTRODUCTION

Analysis of motion and assessment of the effects of internal and external forces on the living body is very important in sports. These biomechanical considerations involve visual observation, and qualitative as well as quantitative analysis of the movements involved (Hamill and Knutzen, 2003). Such analysis provides a better understanding of sports skills and their execution so that teachers, coaches, trainers and others who are involved in sports and exercises can work effectively. Through qualitative analysis an individual can determine the inefficiencies which limit performance in a runner's technique, then work towards eliminating them to enhance performance (Hughes, 2006). The movements of the arms control running by setting the tempo for the legs, generating forward propulsion, lift, drive, and various components of angular momentum about the vertical axis, as well as regulating balance (Dunton, 2003; Hinrichs, 1992). Considering that the overall performance in distance running relies to a large extent on the runner's ability to run economically, conserving energy must therefore be a primary objective of the arm action as it generates various components of running mechanics (Mathews, 2004; Dunton, 2003). The aim of this study was to establish the most efficient arm actions -the arm actions that leads to least physiological demands on long distance athletes (most economical arm action) while performing at a given sub-maximal pace. The study addressed the apparent disparity between some successful athletes' arm action and the recommended arm action in long distance running. While most authors recommend that the arms should be moved back and forth with elbows held at about 90 degrees (Morris, 2010; Mathews, 2004; American Running and Fitness Association, 2000), some distance running athletes have used different arms movements with varying degree of success and failure during several international athletics competitions. Arm swing in running technique is essential in the transfer of angular momentum about vertical axis, between the upper and lower body of the athlete. The balance of angular momentum has been stated as being the most important aspect of arm action in running, for the arms are key in dissipation of total body angular momentum about the vertical axis through athlete's center of mass. Arm swing also counteracts the fairly large

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amount of vertical angular momentum produced by the legs. The resultant amount of vertical angular momentum minimizes the free moment exerted by the runner on the ground. This allows the athlete to only apply forces onto the ground instead of applying both forces and torques. The motion of the arms is therefore necessary in order to enable the legs stride, by generating most of the angular impulse about the vertical axis (Morris, 2010; Robertson *et al*., 2004; Dunton, 2003; Hinrichs, 1992). Hughes (2006) wrote that the arms aid in achieving a constant horizontal velocity, which could lead to a reduction in energy cost, and that as a runner begins to fatigue, the use of arm swing becomes more important, helping the runner to maintain lift and drive. The vigorous backswing of the arms helps to maintain the achieved velocity of the runner as the legs complete the drive.

Energy cost of running can be determined as the ratio of oxygen used to velocity of the movement (Hill and Rowell, 1996; Brisswalter *et al*., 1998) or as the speed at which one can run when using oxygen at a given rate (Crowther, 2001). Measuring running economy is equivalent to measuring how far a person can run using a given amount of energy. The further one can run per unit of oxygen consumed, or the less oxygen he/she consumes in running a given distance, the more economical he/she is (Saunders *et al*, 2004). Considering these statements, one can take volume of oxygen consumed, distance covered, race times, speed, and/or percentage of VO_2 max as indicators or variables in evaluation of running economy, depending on which variables are controlled. Heart rate and blood lactate as well as rating of perceived exertion can also be used as they have been shown to correlate highly with oxygen consumption (VO_2) / energy expenditure at sub-maximal and maximal activity levels (Mackenzie, 2005; Brillharts, 2004; Lucia *et al*., 1999; Hill and Rowell, 1996; Noble and Robertson, 1996; Olivier, 1990). This study therefore sought to assess the effects of different arm actions on running economy (one of the major determinants of performance in long distance running) among Kenyan athletes. It investigated how different arm actions affected cardio-respiratory parameters (related to energy expenditure) and stride patterns during the steady phase of long distance running.

MATERIALS AND METHODS

Experimental research design was used in which some variables in long distance running were controlled to investigate the effects of different arm actions on running economy. Independent variable (treatment/factor) was the different arm actions (directions of arm swing and angles at the elbow) when running. Extent of fore swing was controlled to be up to midline of athlete's body (except in Trial10 -arm action involving lateral movements made with arms held at 90 degrees), and not beyond shoulder height (except in Trial 7 - arm action involving oscillation of elbow angles from 50 to 110 degrees). Dependent variables were the working and recovery heart rate, estimated oxygen consumption, ventilation rate, rating of perceived exertion and stride rate, when running at a constant speed corresponding to 80% of maximum effort (as estimated from 12 minutes Cooper's test run). These were monitored to establish how they were affected by the independent variable. Within–subjects /repeated measures design was used, where same subjects were measured under each of the different test conditions (arm actions). In this design, the subjects served as their own control as they took part in all the test trials. The research design is highly effective in removing the extraneous variability that comes from pre-existing individual differences, as inter-subjects variability is identified and removed during computation. The study design also requires fewer subjects, depending on the number of repeated measures (Lowry, 2005; Thomas *et al*., 2005; Eston and Rowlands, 2000; Vincent, 1995). The study involved 10 subjects, sample size considering the high number (10) of repeated measures in the within-subject research design (Lenth, 2001). The trials were performed in a randomized Latin Square order, to control influence of practice effects / learning related to the testing procedure (to obviate the influence of sequence effects), as recommended by Lowry (2005) and Shaughnessy *et al*. (2003). The study utilized the 'elbow angle-guide' devices which were designed, constructed and used for the first time, to enable the athletes use the required arm action for the different test trials. This made it possible to note the effects of each of the arm action by monitoring and comparing HR, RPE, VR, and SR values. A pair of the device was fixed on the athlete's arms ensuring that its proximal and distal arms were in line with the mechanical axis of the upper and lower arms respectively. The centre of the angle was placed in line with the centre of the elbow joint articulation (head of radius) while the axis of the proximal and distal arms of the device traced the greater tubercle of the humerus and the styloid process of the ulna respectively, borrowing some principles from goniometric placement procedures as described by Scheuchenzuber, (1981).

The angles at the elbows used in the tests Trial1- 6 were 50 degrees, 70 degrees, 90 degrees, 110 degrees, 130 degrees and 150 degrees respectively. They were taken as substantial variation in arm action, 90 degrees being the recommended angle. Angles of 110 degrees and 50 degrees were used to guide extent of vertical oscillations of the hands in Trial7, 90 degrees and 70 degrees in Trial8, and 110 degrees and 70 degrees in Trial9. Lateral movements were made with hands held at 90 degrees in Trial10, the subject maintaining minimal movement of the upper arm. A familiarization session preceded each test trial, where the subject performed the required arm movements without actual running. There was a further 5 minutes warm up session consisting of treadmill run at 60 % speed for the first 2 minutes, increased to 70 % for the next two minutes and to 75 % the next one minute. This enabled the athlete to get accustomed to running with the "new" arm action for the given test trial in addition to the general body warm up, before reaching the 80 % testing pace. Polar Heart Rate Monitor (Polar Accurex II) and Treadmill (Lifefitness, 9000) were used.

The relationships between working heart rate and energy expenditure during exercise have been studied extensively. A high correlation has been found and these studies have led to development of regression equations to describe the relationships;

$\% VO_2 \text{ max} = (\% MHR - 37) / 0.64$ Brillhart, D. (2004)
$VO_2 \text{ max} = (\text{Distance covered in 12 minutes [m]} - 504.9) / 44.73$ Mackenzie, B. (2005)
$\sim 4.82 \text{ kcal} = 1L\ O_2$ Brillhart, D. (2004)

The energy cost of running with each of the ten different arm actions was estimated using these equations and expressed in both percentage of maximum oxygen consumption (% VO_2 max) and kilocalories (Kcl) (Mackenzie, 2005; Brillhart, 2004).

RESULTS

Significant difference was observed in working heart rate (WHR), percent of maximum heart rate (% MHR), estimated percentage of maximum oxygen consumption (% VO_2 max), kilocalories (Kcl) and Rating of Perceived Exertion (RPE) at $p < .01$ while Stride rate (SR) difference was significant at $p < .05$ level. This was after Huynh Feldt adjustments for violation of sphericity, the epsilon (ε) values of .702 to .781 indicating only minor violation. There was no significant difference in recovery heart rate (RHR) and ventilation rate (VR) values, although pairwise comparison with Least Significant Difference showed significant difference in VR at $p < .10$ level between some of the trials. Considerations were made on the possibility of the influence of ventilation depth on VR variability.

Working Heart rate was a major research variable having been shown to correlate highly with rate of energy consumption during physical activities. The working heart rate (WHR) values were also converted to percent of maximum heart rate (% MHR) by taking 220 minus the age of the athlete as the maximum heart rate. This formula is known to give a fairly accurate estimate of this parameter, and has been used widely by researchers as well as trainers (Mackenzie, 2005). As it can be seen in Figure 1 below, Trial 7 (arm action involving oscillation of elbow angles from 50 to 110 degrees) registered the highest working heart rate (and percentage of maximum heart rate) while Trial 8 (arm action involving oscillation of elbow angles from 70 to 90 degrees) recorded the lowest.

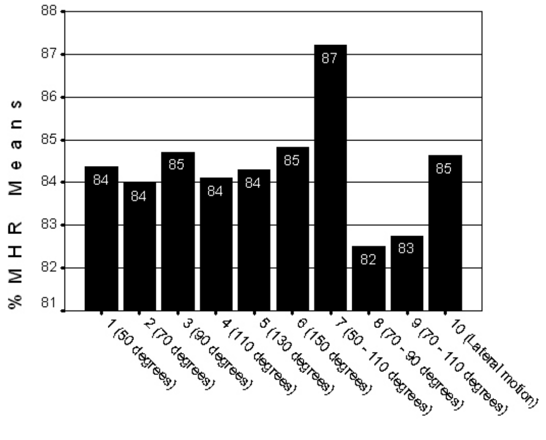

Fig. 1.Maximum Heart Rate Percentage (% MHR) means calculated from working heart rates recorded when using different arm actions (n = 10).F = 3.482 p <.05

Analysis of Variance with Repeated Measures yielded alpha value of $p = .0011$ for maximum heart rate percentage (% MHR) values as shown in Table 1 below. After Greenhouse-Geisser and Huynh-Feldt adjustments for violation of sphericity, the p value attained was .004 and .020 respectively. The Huynh-Feldt epsilon (ε) value (which is multiplied with degrees of freedom (*df*) to correct for violation of the assumption of sphericity) was .74 indicating that there was no severe violation. According to Vincent (1995), as a general rule, if epsilon is equal or greater than .75 ($\varepsilon \geq .75$), the violation is considered minimal.

Table 1; Repeated Measures ANOVA (Tests of Within-Subjects Effects) with Compound Symmetry (Sphericity) assumption taken into consideration. Measure: Maximum Heart Rate Percentage (% MHR) (n = 10). p <.05

Source of Variation		Sum of Squares	*df*	Mean Square	*F*	Sig.
ARM ACTIONS	Sphericity Assumed	148.183	9	16.465	3.482	.001
	Greenhouse-Geisser	148.183	3.715	39.889	3.482	.020
	Huynh-Feldt	148.183	6.651	22.281	3.482	.004
ERROR	Sphericity Assumed	383.040	81	4.729		
	Greenhouse-Geisser	383.040	33.434	11.457		
	Huynh-Feldt	383.040	59.856	6.399		

Just like in the energy cost estimating variables, Trial 7 (arm action involving oscillation of elbow angles from 50 to 110 degrees) recorded the highest rating of perceived exertion (RPE) and Trial 8 (arm action involving oscillation of elbow angles from 70 to 90 degrees) the lowest. Trial 3 (the recommended arm action involving arms held at 90 degrees) rated between the two extremes while Trial 9 (arm action involving oscillation of elbow angles from 70 to 110 degrees) was the second least exerting. The tread is close to that observed in the percentage of maximum heart rate percentage values, but with minor variations, as shown in Figure 2. Significant difference was observed at $p < .05$.

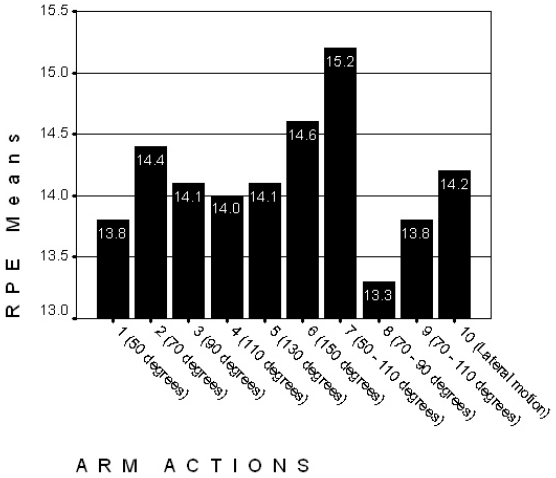

Figure 2; Rating of Perceived Exertion (RPE) recorded when using different arm actions (n = 10). F = 3.718 p <.05

Stride pattern (stride rate and length) was taken as an important aspect of the overall running technique. The optimum stride length for most runners occurs subconsciously, and is developed with practice over time. According to Williams and Cavannagh (1987 page 1239), Stride length (SL) can be calculated as; SL = V **x** ST (where V is the treadmill speed, and ST is the step time -time between successive foot strikes). It can also be derived from the formula / relationship described by Hamill and Knutzen (2003 page 290); Running speed = Stride length **x** Stride rate. A change from the optimum stride either by lengthening or shortening can cause energy cost of running to rise (Anderson, 2008; Hughes, 2006). Over-striding can be energy costly due to the foot-strike deceleration it causes. Using shorter strides would on the other hand expend more energy due to more muscular activity at a given running pace. The stride rate values recorded in the different trial runs are shown in Figure 3 below.

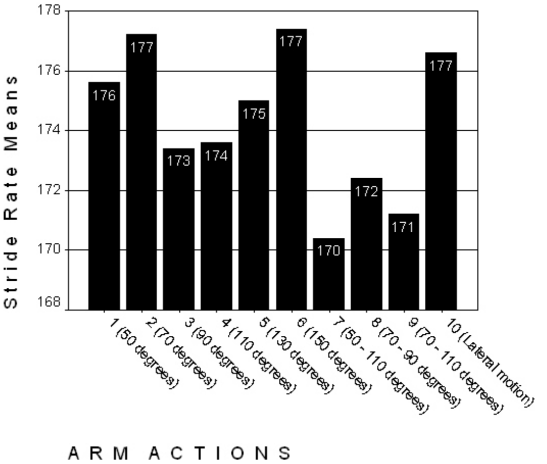

Fig. 3. Stride rates (SR) recorded when using different arm actions (n = 10). F =2.410 p < .10

There was significant difference in stride rate between various trials at p < .10 level (F = 2.410). Most notable observation was that Trial 7 (arm action involving oscillation of elbow angles from 50 to 110 degrees), which proved to be most costly arm action for the sub-maximal pace, recorded the lowest stride rate. Trial 6 (arm action involving arms held at elbow angle of 150 degrees) recorded the highest. Pairwise comparison with Least Significant Difference showed that running with arms held at 90 degrees (as recommended by most biomechanics authors and coaches) is more costly than running with arms oscillation of 70 to 90 degrees at the elbows as indicated by the difference in % MHR (p = .039), % VO_2 Max (p = .039), RPE (p = .046) and Kcl expended (p = .041). There was no significant deference in terms of ventilation rate and in stride rate between the two arm actions (p = .425 and 0.715 respectively). Running with arms oscillation of 50 to 110 degrees at the elbows was the most costly arm action. Arm action involving arms oscillation of 70 to 90 degrees at the elbows was the most economical followed closely by the one involving arms oscillation of 70 to 110 degrees. Effect size calculated from % MHR data to determine the practical significance yielded Eta Squared (R^2) value of .28, and Omega Squared (ω^2) value of .20. This is a medium effect size indicating that about 20% proportion of variability can be attributed to change in arm action alone.

DISCUSSION

Mechanics of movement do have an influence on the metabolic costs of running, as shown by several studies (Morris, 2010; Hughes 2006; Dunton, 2003; Williams and Cavanagh, 1987). It is then expected that an improvement in an individual's running mechanics would result in less energy costs, and would allow for better performances (Williams and Cavanagh, 1987). A more efficient runner is able to run at a faster pace since a relatively lower percentage of their VO_2 max is being utilized (Hughes 2006). This study looked at the basic biomechanics of long distance running with reference to arm action in relation to running economy. It aimed at determining efficient arm movements for long distance running. Subjects were tested in ten treadmill trial runs using different forms of arm action for each. Each subject was tested at 80% of their maximum effort in all the ten trials, calculated from the 12 min distance trial. This ensured that each of the subjects was tested while working at his/her own sub-maximal pace. It overcame the testing-related limitations cited by Williams and Cavanagh, (1987) where 'performance times were compared with biomechanical data for which all subjects run at the same speed' (page 1243), and where the biomechanical data was compared to performance times recorded in different trials.

Possible explanation for the results could be that, more contribution to 'lift' by vertical oscillations of the hand as compared to fixed elbow angles may have led to more economical running hence lower values of % MHR and RPE in trials 8 and 9. According to Moreau (2005), the arms help the legs in propelling the body upward by providing lift to the runner, leaving the legs to provide more drive. This means that the legs will have less work to do in attempting to push the body upward, and can then be left to concentrate on propelling the body forward. Excessive lift is indicated in Trial 7 by decrease in stride rate for the same speed (increase in stride length and stride time), meaning that more time was spent in the air, causing extra energy to be expended beyond that required for the pace/trial speed. This agrees with the fact that, arm swings with wide range of elbow angle change and long strides is normally observed when running at high speed – in sprints or during the final kick/phase of distance races. Here the arm action contributes not only to lift, but more to forward angular momentum and propulsion since the athlete adopts more forward lean body carriage. It is logical to say that the longer stride time at the given running pace in Trial 7 was accompanied by more loss of speed due to longer airborne phase of the running cycle, resulting to more deceleration and acceleration with every stride, these impacting negatively on running economy (RE). Hughes (2006) states that over-striding can be energy costly due to the foot-strike deceleration it causes.

Aiding of blood flow in the upper extremities by the contracting and relaxing muscles of the arm may also be responsible for lower values in trials 8 and 9, as compared to the trials which were performed using arm actions with fixed angle at the elbows (trials 1-6). Timing of changing angle at the elbow may also contribute to more efficient kinematics compared to using a fixed angle. The increased force of inertia of the arm during backswing as a result of lengthened arm (through widening of elbow angle) displaces the trunk in forward direction easily, thereby generating more forward angular momentum about vertical axis. Bending/shortening of the arm (decreased inertia) by narrowing of elbow angle during forward swing ensures that the attained forward momentum is not counteracted by equal and opposite forces of the athletes' two arms.

Although Trial 8 (arm action involving oscillation of elbow angles from 70 degrees – 90 degrees) registered the lowest % MHR and RPE, when the results are considered against overground running as opposed to treadmill running, Trial 9 (arm action involving oscillation of elbow angles from 70 degrees – 110 degrees) may be more economical. This is because the arms' contribution to angular momentum about the vertical axis through an individual's center of mass is required more during overground running than on treadmill run. During treadmill run, the backward motion of treadmill belt aids in displacing upper body forwards, thereby reducing the arms requirement of displacing the upper body over the driving legs. A runner has to constantly alter the lever-arms of the force components by adjusting the position of his center of gravity in relation to his supporting foot. This is achieved through changing angle of his trunk mainly through arm swings. To maintain the trunk in this efficient running position, the legs and arms take up these angular moments (Dyson, 1986). It is important to note that by the time the arm moves past 90 degrees the centre of mass of the arm is moving more backwards than downwards in relation to the athlete's centre of mass, thus contributing more to angular motion than to 'lift'.

The results obtained from the current study agree with Hughes (2006) who wrote that the angle of arm flexion should be around 90 degrees but should allow for some movement on either side of it. The author says that this will help to smooth out the form and avoid robot arm action and emphasizes that the arms do play vital role in running and are not just merely used for balance. Practical limitations included controlling and accounting for the extent of elbow excursion (forward, backward and/or lateral movement), but athletes were instructed not to swing the hands beyond shoulder height or beyond their anterior midlines. It is also likely that those who have a habit of or are used to running with wide range (or any particular pattern) of arm and shoulder movement applied it across all the test trials, thereby having no adverse effects on the differences observed. Ventilation depth was also not controlled or accounted for. This influenced data as an intervening variable resulting to ventilation rate difference observed being insignificant. Huynh-Feldt epsilon (ε) value of .251 indicates a lot of violation for the assumption of compound symmetry, meaning that ANOVA with repeated measures could not be used accurately in determining significance for this variable. However, multiple comparisons with Least Significant Difference adjustments indicated significant mean difference at the $p < .10$ level between some of the trials.

The study concluded that steady state distance running with arm swing consisting of elbow angle oscillation around 90 degrees is more economical than running with the arm 'held' at 90 degrees which is recommended by many biomechanics, authors and coaches However, arm action consisting of either wide angle of oscillation at the elbow or excessive lateral motions of the hand results to more energy consumption. The study also concludes that variation in arm action affects the whole of the running technique as indicated by significant difference in stride rate/length/time at a given constant pace, and therefore impacts negatively or positively on the energy cost of running. Further studies need to be done to focus on other angles around 90 degrees not covered by the current study, as well as to combine investigations on arm action with lower extremities kinetics such as ground reaction forces. This would lead to more understanding of their interactions and their contribution to overall performance in distance running. Similar study should be conducted with the athletes running overground as opposed to treadmill running. Use of telemetric measurements systems in such studies should also be done for actual activity and real time assessments. These would lead to more clarity of mechanical profile of an economical distance running technique.

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