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The RunSmart training program: effect on oxygen consumption and lower extremity biomechanics during running

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As recreational running continues to gain popularity, more individuals are seeking ways to improve running performance. RunSmart is a running intervention program designed to enhance a runner's form. In addition to correcting flaws in a runner's form, RunSmart offers the opportunity for runners to continue a regular regimen while slowly integrating changes in form. The purpose of this case series was twofold: to determine if the RunSmart program coincides with improvements in oxygen consumption (VO₂), a variable often associated with better running performance times, and to evaluate the RunSmart program in regard to enhancing gait biomechanics. Five recreational runners volunteered to participate in this program. Subjects initially reported to the clinic for an initial submaximal VO₂ treadmill test and lower extremity biomechanical analysis. After the initial testing session, each subject attended one session of one-on-one individualized RunSmart instruction per week for 6 weeks. At the first RunSmart session, subjects received a biomechanical analysis to determine their foot strike pattern and areas of muscular weakness and range of motion limitations. Throughout the 6-week run-

ning program, participants ran 5 days every week for predetermined times each day; 2 runs every week were designated as interval training runs. Subjects then underwent a follow-up submaximal VO₂ treadmill test and lower extremity biomechanical analysis at the end of 6 weeks. Descriptive statistics were used to assess data pertaining to VO₂ and biomechanical analysis and compare initial and follow-up testing sessions. Following completion of the RunSmart program, subjects demonstrated improvements in VO₂ and also improved several biomechanical factors related to the lower extremity running gait. Based on the results from this case series, the RunSmart training program may have the potential to change a runner's form and improve VO₂, thus resulting in improved distance running times. However, this is speculation given the nonexperimental nature of this case series. Future research on this topic should include a greater number of participants in randomized controlled trials on injury prevention and running efficiency.

Keywords: Running, Oxygen consumption, Biomechanics

INTRODUCTION

As recreational running continues to gain popularity, more individuals are seeking ways to improve running performance. Variables believed to influence performance include gait kinematics, biomechanical factors, and various intervention strategies. Stride length, stride rate, vertical oscillation, arm movement, and range of motion of lower extremity joints all appear to influence performance. However, there is some disagreement among researchers

as to which variables are most important for running performance; furthermore, few studies have examined the effect of foot strike patterns on running performance (Anderson, 1996; Cavagna et al., 1964; Cavanagh et al., 1977; Cavanagh and Williams, 1982; Heise and Martin, 1998; Nummela et al., 2007; Tartaruga et al., 2012; Williams and Cavanagh, 1987). Based on the lack of definitive evidence for one specific variable that influence a runner's efficiency, further research is needed to analyze alternative variables, foot strike patterns, and knee extension angle at initial contact.

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Additionally, further research is needed to investigate running economy intervention programs, such as RunSmart, that address these biomechanical variables.

RunSmart is a running intervention program designed to enhance a runner's form, particularly foot strike pattern. In addition to a regular running regimen, this program adds individualized drills and strengthening exercises to transition the runner from a rear-foot to mid-foot strike pattern as well as optimize other aspects of a runner's form that influence running performance. Based on video analysis of a runner's form, a physical therapist identifies biomechanical variables hindering a runner's optimal performance and then structures an intervention program designed to address those specific deficiencies. In addition to correcting flaws in a runner's form, RunSmart offers the opportunity for runners to continue a regular regimen while slowly integrating the changes in form addressed by the prescribed exercises. The purpose of this case series was twofold: (a) to determine if the RunSmart program coincides with improvements in oxygen consumption (VO_2), a variable often associated with better running performance times, and (b) to evaluate the RunSmart program in regard to enhancing gait biomechanics.

MATERIALS AND METHODS

Subjects

Subjects were recruited with the use of an informational flyers distributed at the Young Men's Christian Association of Williamsville, NY, Checkers Running Club, and Buffalo Triathlon Club. Inclusion criteria included age between 30 and 40 years, less than 5 years of running experience, weekly running distances of 40 to 56 km, the ability to run 60 min continuously without stopping, never receiving previous training on proper running form and willingness to complete the 6-week RunSmart training program. Exclusion criteria included a history of spine or lower extremity surgery within the last year, injury/trauma to the spine or lower extremity within the last 6 months, neuromuscular disorders, or systemic disease. Subjects were asked to not complete any other additional training or participate in races during the 6-week program. Informed consent and a health history form were obtained prior to the initial testing. Subjects reported to the clinic for an initial submaximal VO_2 treadmill test and lower extremity biomechanical analysis, then they attended a RunSmart session once a week for 6 weeks, and then underwent a follow-up submaximal VO_2 treadmill test and lower extremity biomechanical analysis at the end of 6 weeks.

Initial testing

Data collection for each subject occurred during an initial visit lasting approximately 1 hr. Subjects were asked to wear their preferred running shoes for treadmill testing. For testing, reflective tape was affixed to the following locations: left lateral malleolus, midpoint of left lateral knee joint, and left greater trochanter. Markers provided points in which to calculate ankle dorsiflexion angle at initial contact, knee extension angle at initial contact, and maximal hip and knee flexion angles during swing phase during the treadmill test.

During data collection, subjects wore a heart rate monitor that was calibrated with the Med Graphics VO2000, a portable device measuring the gas exchange and energy expenditure at rest and during activity. Med Graphics VO2000 uses a galvanic fuel cell oxygen analyzer and a nondispersive infrared carbon dioxide analyzer as well as a respirator mask to measure oxygen and carbon dioxide volumes used and expelled during running (Wahrlich et al., 2006). Subjects were assessed during 3 stages. Subjects began testing by walking at a fast pace on a treadmill at a 1% grade for 2 min, which was stage 1. After 2 min, treadmill speed increased to a slow jog/fast walk pace for another 2 min, which was stage 2. As testing progressed, subjects reported rate of perceived exertion on a 0 to 10 scale. At 2-min intervals, treadmill speed increased until the subject was running at a pace consistent with a 7 or 8 on the rate of perceived exertion scale. At each speed, interval heart rate, VO_2 , and carbon dioxide expiration values were collected. Testing progressed until each subject reached threshold (stage 3), which was the point at which VO_2 significantly declined and anaerobic respiration occurs. Data collected at this point represented the amount of oxygen consumed at a specific treadmill speed.

While running, subjects were filmed using a video camera at two different speeds: once when they began running and once when they had reached the maximal treadmill speed. Video analysis with Dartfish Software recorded ankle dorsiflexion angle at initial contact, knee extension angle at initial contact, and maximal hip and knee flexion angles during swing phase. Following testing, each participant received an analysis of heart rate levels to be used in a 6-week training schedule. A copy of the specific running schedule is included in the Appendix.

Intervention

After the initial testing session, each subject attended one session of one-on-one individualized RunSmart instruction per week for 6 weeks. At the first RunSmart session, subjects received a biomechanical analysis to determine their foot strike pattern and

areas of muscular weakness and range of motion limitations. Following biomechanical analysis in the first session, subjects were instructed to transition gradually to a midfoot strike; a slow, gradual transition was recommended in order to avoid injury. To transition from a heel strike to a midfoot strike, runners were taught to land with the shin in a vertical position; runners practiced this landing pattern while walking and progressively increased their speed so that the pattern was incorporated into their running. Runners were also encouraged to increase the amount of knee flexion and hip flexion during swing to maximize running efficiency. To prevent injury and excessive muscle soreness, runners were sent home with instructions to run in intervals; 3 min with a midfoot strike followed by 1 min of running their “old way.” In subsequent sessions, training was focused on muscular weakness and range of motion limitations; runners were also assessed each week to ensure that they were effectively incorporating the new foot strike pattern and run form. Strengthening and range of motion exercises addressed subjects’ specific impairments and were individualized to each participant.

Throughout the 6-week running program, participants ran 5 days every week for predetermined times each day; two runs every week were designated as interval training runs. Following initial data collection each subject was provided with 5 heart rate zones specific to their VO_2 threshold. Each zone was based on a percentage of a subject’s heart rate at VO_2 threshold: zone 1 was < 75%, zone 2 was 75% to 80%, zone 3 was 81% to 85%, zone 4 was 86% to 90%, and zone 5 was 91% to 100%. Each run on the training schedule dictated which heart rate zones subjects needed to attain. Runners tracked heart rate with heart rate monitors during every run to ensure that they remained within the designated heart rate zone. After each run, participants recorded mileage, average heart rate, and pace.

Follow-up testing

After completion of the 6-week RunSmart program, subjects returned to the initial data collection site for follow-up measurements, which followed the same treadmill protocol as with initial testing and the Med Graphics VO2000 device collected measurements of heart rate, VO_2 , and carbon dioxide consumption. Video analysis recorded any changes in ankle dorsiflexion angle at initial contact, knee extension angle at initial contact, and maximal hip and knee flexion angles during swing phase following completion of the RunSmart program.

Table 1. Physical characteristics of participants

Subject No.	Age (yr)	Sex	Height (cm)	Weight (kg)
1	30	Male	152.4	90.7
2	29	Female	172.7	68.5
3	40	Male	172.7	88.9
4	34	Male	175.6	84.8
5	37	Male	180.3	112.9
Mean±SD	34±4.6		170.7±10.7	89.2±15.9

SD, standard deviation.

Data analysis

Descriptive statistics were used to assess data pertaining to VO_2 and biomechanical analysis, which were analyzed at 3 different stages. Stage 3 represented the speed at which threshold VO_2 occurred during initial and follow-up testing, while stages 1 and 2 represented the two preceding treadmill speeds prior to threshold. Threshold VO_2 refers to the point when subjects transitioned from aerobic respiration to anaerobic respiration as determined by volumetric measurements of oxygen and carbon dioxide. For data analysis purposes, treadmill speeds between initial and follow-up testing for the 3 stages remained consistent to allow comparison of initial and final VO_2 at each stage.

RESULTS

Subjects

Eight subjects volunteered for this program. Two subjects did not complete the program due to absence from the RunSmart sessions and one person was unable to complete the program as a result of a knee injury obtained outside of training. Thus, 5 subjects completed the program. Demographic characteristics are provided in Table 1.

Oxygen consumption

The mean absolute threshold for VO_2 improved from initial to follow-up testing (Tables 2, 3). Table 2 represents the VO_2 at each stage during initial and final testing as well as the threshold VO_2 at final testing if subjects improved the speed at which they reached threshold values. Mean absolute threshold VO_2 at final testing was 3,432.9 mL/min, improved from 3,144.6 mL/min at the time of initial testing; further analysis indicated that 4 of the 5 subjects increased their absolute threshold VO_2 (Table 2). Also, at the time of follow-up, the mean threshold VO_2 was 91.7% during stage 3; 3 subjects (1, 3, and 5) improved their threshold VO_2 percentage from initial to final testing. This indicates a lower

Table 2. Oxygen consumption for each of the 3 stages during initial and follow-up testing, as well as the threshold oxygen consumption (VO₂) at follow-up testing; all subjects except subject 4 improved the speed at which they reached threshold values

Subject No.	Initial VO ₂ submaximal (mL/min)			Follow-up VO ₂ submaximal (mL/min)			
	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Threshold
1	2,481.2	2,816.0	2,895.3	2,384.0	2,844.0	3,226.0	3,337.0
2	2,292.3	2,681.3	3,136.1	2,701.4	3,003.4	3,186.0	3,186.0
3	2,191.1	2,883.2	3,105.3	2,377.0	2,890.6	3,266.5	3,693.8
4	3,860.1	4,234.6	4,372.9	4,123.5	4,196.4	4,261.9	4,261.9
5	2,016.5	2,170.0	2,213.3	2,482.9	2,527.4	2,577.0	2,685.6
Mean±SD	2,568.2±741.5	2,957.0±766.0	3,144.6±780.0	2,813.8±743.8	3,092.4±641.9	3,303.5±605.7	3,432.9±588.2

Table 3. Percent of the threshold oxygen consumption reached at each of the three stages of testing

Subject No.	Initial testing			Follow-up testing		
	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
1	85.7	97.3	100	71.4	85.2	74.9
2	73.1	85.5	100	84.8	94.3	100
3	70.6	92.9	100	64.4	78.3	88.4
4	88.3	96.8	100	96.8	98.5	100
5	91.1	98.0	100	92.5	94.1	95.0
Mean±SD	81.2±9.3	94.1±5.2	100±0	82.0±13.8	90.1±8.2	91.7±10.5

SD, standard deviation.

Table 4. Maximal angles of ankle dorsiflexion, knee extension, knee flexion and hip flexion during initial and follow-up testing

Subject No.	Initial testing				Follow-up testing			
	Ankle dorsiflexion (°)	Knee extension (°)	Knee flexion (°)	Hip flexion (°)	Ankle dorsiflexion (°)	Knee extension (°)	Knee flexion (°)	Hip flexion (°)
1	10.7	173.3	105.9	32.2	2.7	163.1	111.4	42.4
2	9.6	170.5	93.9	31.4	-15.3	169.3	114.4	41.1
3	7.7	177.5	107.6	26.8	-12.3	168.9	105.7	34.8
4	7.8	174.1	93.7	27.9	-4.2	170.7	103.2	38.5
5	10.4	171.9	89.9	29.5	-5.9	164.9	105.1	32.8
Mean±SD	9.2±1.4	173.5±2.6	98.2±8.0	29.6±2.3	-7.0±7.1	167.4±3.2	108.0±4.7	37.9±4.1

SD, standard deviation.

threshold percentage of VO₂ submaximal at the corresponding stage of initial testing, suggesting that subjects required a smaller percentage of their threshold VO₂ to run at the same speed during initial testing (Table 3).

Lower extremity biomechanical analysis

Maximal angles of ankle dorsiflexion, knee extension, knee flexion, and hip flexion during initial and follow-up testing are presented in Table 4. Subjects demonstrated less knee extension at initial contact during the follow-up testing session (167.4° vs. 173.5°). Less knee extension at initial contact also corresponded to decreased ankle dorsiflexion and midfoot striking. All participants except for subject 3 achieved a greater degree of knee flexion

during swing phase; greater knee flexion requires less energy expenditure in order to drive the leg forward for initial contact. Subjects also achieved a greater degree of maximal hip flexion during swing phase, which allows the lower leg to be carried through swing by momentum and positioned in a more optimal position for initial contact.

DISCUSSION

The purpose of this case series was twofold: (a) to determine if the RunSmart program coincides with improvements in VO₂, a variable often associated with better running performance times, and (b) to evaluate the RunSmart program in regard to enhancing

gait biomechanics. Following completion of the RunSmart program, subjects demonstrated improvements in VO_2 and also improved several biomechanical factors related to the lower extremity running gait.

Trends show that runners completing the program displayed decreased ankle dorsiflexion and increased knee extension at initial contact as well as increased hip and knee flexion during swing phase. During the RunSmart training program, runners were instructed to transition to a midfoot strike. To transition from a heel strike to a midfoot strike, runners were taught to land with the shin in a vertical position; runners practiced this landing pattern while walking and progressively increased their speed so that the pattern was incorporated into their running. Runners were also encouraged to increase the amount of knee flexion and hip flexion during swing to maximize running efficiency. In subsequent sessions, training was focused on muscular weakness and range of motion limitations; runners were also assessed each week to ensure that they were effectively incorporating the new foot strike pattern and run form. Therefore, based upon the data in this case series, the RunSmart training program appeared to positively alter the gait biomechanics of the subjects. Furthermore, mean absolute threshold VO_2 and mean threshold VO_2 percentage improved from initial to follow-up testing. Although there was some inter-subject variation for changes in VO_2 , the results demonstrate a trend for improved VO_2 with positive alterations in gait biomechanics following completion of the RunSmart program.

Cavanagh et al. (1977) compared biomechanical variables such as foot strike and shank angle at initial contact and knee and hip flexion during swing phase of gait between elite and good runners. Researchers concluded that elite runners, compared to good runners, exhibited greater knee and hip flexion during swing phase and greater knee extension and decreased ankle dorsiflexion at initial contact; however, the relationship between efficiency and these biomechanical variables were only moderate in strength (Cavanagh et al., 1977). In comparison, the subjects in this case series demonstrated less knee extension and less ankle dorsiflexion at initial contact as well as greater hip and knee flexion during swing phase. These improvements also appeared to correspond with improved VO_2 , suggesting improved running economy.

A potential explanation for the difference in results between studies is the classification of runners into good and elite status by Cavanagh et al. (1977). Instead of recruiting runners meeting the good or elite qualifications, the subjects in the present case series had limited running experience based on the assumption that less experienced runners would more readily be able to change their

running form as well as display greater changes in VO_2 . Similar to Cavanagh et al. (1977), Williams and Cavanagh (1987) compared 3 groups of runners based on efficiency and found that better runners displayed shank angles further away from vertical indicating greater knee extension moment at initial contact. However, the difference in shank angle between each group of runners was less than 3 degrees and not clinically significant (Williams and Cavanagh, 1987). Runners in the present case series were encouraged to strike the ground with their tibia perpendicular to the running surface. It has been hypothesized that greater knee extension leads to a rear-foot strike pattern at initial contact and creates a braking force at the ankle and knee joint. This braking force is not only detrimental to lower extremity joints but this force also decreases running efficiency by forcing the runner to overcome the negative braking force needed to propel forward. Additionally, in a recent study by Goss and Gross (2013), they concluded that Chi runners, or runners landing with a midfoot or fore-foot strike pattern experienced less negative work around the knee joint thus decreasing the amount of quadriceps work and enhancing efficiency. Runners gain efficiency by decreasing the amount of energy required to create a forward propulsive moment. By manipulating biomechanical variables associated with decreased muscular recruitment and force generation, runners decrease their energy demand thus improving efficiency and improving VO_2 .

Runners in this case series were encouraged to increase the amount of knee flexion and hip flexion during swing to maximize running efficiency. It has been hypothesized that greater knee flexion during swing phase decreases the moment arm of gravity acting on the lower leg. As a result, knee flexors require less energy to overcome gravity and hip flexors advancing the limb require less force to swing the limb forward. Additionally, greater hip flexion drives the swing leg forward creating a more powerful extension moment in the planted limb due to an increased crossed extension response. Greater extension moment in the plant limb may result in greater forward propulsion and an increase the amount of momentum produced, thus decreasing the amount of muscular energy needed for propulsion.

Limitations in the present study should be considered. The most obvious limitation in the present study is the small sample size ($n = 5$). Given the small sample size which included healthy subjects, the external validity is limited and caution should be used in interpreting the results. Throughout the training period, exercise variables were monitored via patient report. Participants may not have stayed in the designated heart rate zone, completed the proper workout, ran with appropriate form, or performed the

necessary exercises as instructed. Additionally, the 6-week study period may not have been a substantial amount of time to maximize changes in VO_2 or biomechanical factors. Moreover, this time period may not have been long enough for a person to conceptually understand a new running style and physically perform the necessary training regime consistently and accurately.

Based on the results from this case series, the RunSmart training program may have the potential to change a runner's form and improve VO_2 , thus resulting in improved distance running times. However, this is speculation given the nonexperimental nature of this case series. Future research on this topic should include a greater number of participants in randomized controlled trials with long-term follow-up on injury prevention and running efficiency.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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Appendix. Target heart rate zones, weekly running schedule, and participant daily running log

Heart Rate Zones	Min	Max
Zone 1	< 75%	
Zone 2	75%	80%
Zone 3	81%	85%
Zone 4	86%	90%
Zone 5	91%	100%

	Run 1	Run 2	Run 3	Run 4	Run 5	Total Time
	Target					
Time	50	40	55	40	80	265
Heart Rate Zone	Warm-up 10 minutes easy. Then do 4 x 2 minutes. Build to heart rate zone 4 (2 minute recoveries). Relaxed form.	Zone 1 - 2	Warm up 10 minutes, then zone 1-2 and then 10 minutes in zone 3 with a continuous heart rate. Mostly flat. Remainder zone 2.	Zone 1 - 2	Zone 1 - 2	
Post Run Data						
Time						
Miles						
Avg Heart Rate						
Pace						

	Run 1	Run 2	Run 3	Run 4	Run 5	Total Time
	Target					
Time	55	45	60	40	90	290
Heart Rate Zone	Warm-up 10 minutes easy. Then do 4 x 3 minutes. Build to heart rate zone 4 (2 minute recoveries). Remainder in zone 1 - 2.	Zone 1 - 2	Warm up 10 minutes, then zone 1-2 and then 15 minutes in zone 3 with a continuous heart rate. Mostly flat. Remainder zone 2.	Zone 1 - 2	Zone 1 - 2	
Post Run Data						
Time						
Miles						
Avg Heart Rate						
Pace						

	Run 1	Run 2	Run 3	Run 4	Run 5	Total Time
	Target					
Time	60	45	60	45	100	310
Heart Rate Zone	Warm-up 10 minutes easy. Then do 4 x 4 minutes. Build to heart rate in zone 4 (3 minute recoveries). Remainder in zone 1 - 2.	Zone 1 - 2	Warm up 10 minutes, then zone 1-2 and then 20 minutes in zone 3 with a continuous heart rate. Mostly flat. Remainder zone 2.	Zone 1 - 2	Zone 1 - 2	
Post Run Data						
Time						
Miles						
Avg Heart Rate						
Pace						

	Run 1	Run 2	Run 3	Run 4	Run 5	Total Time
	Target					
Time	40	35	50	35	70	230
Heart Rate Zone	Warm-up 10 minutes easy. Then do 4 x 2 minutes. Build to heart rate in zone 4 (2 minute recoveries). Remainder in zone 1 - 2.	Zone 1 - 2	Warm up 10 minutes, then zone 1-2 and then 10 minutes in zone 3 with a continuous heart rate. Mostly flat. Remainder zone 2.	Zone 1 - 2	Zone 1 - 2	
Post Run Data						
Time						
Miles						
Avg Heart Rate						
Pace						

(Continued to the next page)

Appendix. Continued

		Run 1	Run 2	Run 3	Run 4	Run 5	Total Time
Week 5		Target					
	Time	60	50	60	50	110	330
	Heart Rate Zone	Warm-up 10 minutes easy. Then do 4 x 5 minutes. Build to heart rate in zone 4 (3 minute recoveries). Remainder in zone 1 - 2.	Zone 1 - 2	Warm up 10 minutes, then zone 1-2 and then 20 minutes in zone 3 with a continuous heart rate. Mostly flat. Remainder zone 2.	Zone 1 - 2	Zone 1 - 2	
		Post Run Data					
	Time						
	Miles						
	Avg Heart Rate						
Pace							
		Run 1	Run 2	Run 3	Run 4	Run 5	Total Time
Week 6		Target					
	Time	60	50	60	50	110	330
	Heart Rate Zone	Warm-up 10 minutes easy. Then do 4 x 6 minutes. Build to heart rate in zone 4 (3 minute recoveries). Remainder in zone 1 - 2.	Zone 1 - 2	Warm up 10 minutes, then zone 1-2 and then 30 minutes in zone 3 with a continuous heart rate. Mostly flat. Remainder zone 2.	Zone 1 - 2	Zone 1 - 2	
		Post Run Data					
	Time						
	Miles						
	Avg Heart Rate						
Pace							