2011-08-03

Kinematic Changes During a Marathon for Fast and Slow Runners

Maggie Man-Yee Chan-Roper
Brigham Young University - Provo

Kinematic Changes during a Marathon for Fast and Slow Runners

Maggie M. Chan-Roper

A thesis submitted to the faculty of

Brigham Young University

In partial fulfillment of the requirements for the degree of

Master of Science

Matthew K. Seeley, Chair

Iain Hunter

Joseph W. Myrer

Department of Exercise Sciences

Brigham Young University

December 2011

ABSTRACT

Kinematic Changes during a Marathon for Fast and Slow Runners

Maggie M. Chan-Roper
Department of Exercise Sciences, BYU
Master of Science

The purpose of this study was to describe kinematic changes that occur during an actual marathon. We hypothesized that (1) certain running kinematic measures would change between miles 5 and 25 of a marathon and (2) fast runners would demonstrate smaller changes than slow runners. Subjects (n = 179) were selected according to finish time (Range = 2:20:47 to 5:30:10). Two high-speed cameras were used to measure sagittal-plane kinematics at miles 5 and 25 of the marathon. The dependent variables were stride length, ground time, peak knee flexion during support and swing, and peak hip flexion and extension during swing. Two-tailed paired t-tests were used to compare dependent variables between miles 5 and 25 for all subjects, and regression analyses were used to determine whether faster runners exhibited smaller changes (between miles 5 and 25) than slower runners. For all runners, every dependent variable changed significantly between miles 5 and 25 ($p < 0.001$). Stride length increased 1.3%, ground time increased 13.1%, peak knee flexion during support decreased 3.2%, and peak hip extension, knee flexion, and hip flexion during swing decreased 27.9%, increased 4.3%, and increased 7.4%, respectively ($p<0.001$). Among these significant changes, all runners generally changed the same from miles 5 to 25 except that fast runners decreased peak knee flexion during support less than the slow runners ($p < 0.002$). We believe these kinematic changes were an attempt by all runners (fast and slow) to decrease energy expenditure and enhance performance at the late stage of the race. The fact that fast runners maintained knee flexion during support more consistently might be due to their condition on the race day. Strengthening of knee extensor muscles may facilitate increased knee flexion during support throughout a marathon.

Keywords: fatigue, endurance, run, biomechanics, race

ACKNOWLEDGEMENTS

Special thanks to Dr. Seeley for his time and encouragement in the revision of this thesis time after time, Dr. Hunter for his amazing expertise in the development of the methods and analysis of this thesis, Dr. Myrer for his support and enthusiasm during the revision process, Dr. Eggett for his masterful statistical analysis, and Dr. Feland for being there to speed up the approval process whenever needed.

Special thanks to Matt Denning, Adam Baron, Jordan Pitt, Silas Klaver and Ryan Stromberg of the Brigham Young University Exercise Science Department for their help related to data collection and analysis.

Additionally, extra thanks to my husband, Brent Roper, for being my sounding board and my three adorable children for enduring their overly-stressed mom throughout the whole program.

Finally, thanks to Brigham Young University for the opportunities to be educated, learn the Gospel and find happiness in life.

Table of Contents

Page

List of Tables

List of Figures

Kinematic Changes during a Marathon for Fast and Slow Runners

Maggie M. Chan-Roper, MS, Exercise Sciences, Brigham Young University

Matthew K. Seeley, PhD, Exercise Sciences, Brigham Young University

Iain Hunter, PhD, Exercise Sciences, Brigham Young University

Joseph W. Myrer, PhD, Exercise Sciences, Brigham Young University

Correspondence: Maggie M. Chan-Roper

2066 West 1730 North

Provo, Utah 84604

(801) 361-6498

Email: mchanroper@gmail.com

ABSTRACT

The purpose of this study was to describe kinematic changes that occur during an actual marathon. We hypothesized that (1) certain running kinematic measures would change between miles 5 and 25 of a marathon and (2) fast runners would demonstrate smaller changes than slow runners. Subjects (n = 179) were selected according to finish time (Range = 2:20:47 to 5:30:10). Two high-speed cameras were used to measure sagittal-plane kinematics at miles 5 and 25 of the marathon. The dependent variables were stride length, ground time, peak knee flexion during support and swing, and peak hip flexion and extension during swing. Two-tailed paired t-tests were used to compare dependent variables between miles 5 and 25 for all subjects, and regression analyses were used to determine whether faster runners exhibited smaller changes (between miles 5 and 25) than slower runners. For all runners, every dependent variable changed significantly between miles 5 and 25 ($p < 0.001$). Stride length increased 1.3%, ground time increased 13.1%, peak knee flexion during support decreased 3.2%, and peak hip extension, knee flexion, and hip flexion during swing decreased 27.9%, increased 4.3%, and increased 7.4%, respectively ($p<0.001$). Among these significant changes, all runners generally changed the same from miles 5 to 25 except that fast runners decreased peak knee flexion during support less than the slow runners ($p < 0.002$). We believe these kinematic changes were an attempt by all runners (fast and slow) to decrease energy expenditure and enhance performance at the late stage of the race. The fact that fast runners maintained knee flexion during support more consistently might be due to their condition on the race day. Strengthening of knee extensor muscles may facilitate increased knee flexion during support throughout a marathon.

INTRODUCTION

Marathon running is becoming an increasingly popular sport. In 2001, the five most well-known marathons in the world—Boston, Chicago, Berlin, London and New York City—had a total of 121,291 finishers. In 2010, the total finishers of these marathons increased by over 43% to 173,958. Marathon running involves a challenging distance (26.2 miles) and produces physiological changes that may alter running biomechanics during the race (Hausswirth and Lehénaff, 2001).

Kinematics and economy of prolonged running have been extensively studied. Most runners choose their stride length (SL) to optimize their running economy throughout a race when running non-fatigued (Cavanagh and Williams, 1982). When running fatigued, however, neither decreased SL (Kyröläinen et al., 2000; Elliot and Roberts, 1980) nor increased SL (Hunter and Smith, 2007) affect running economy. Ground time (GT) increases slightly as fatigue occurs (Elliot and Roberts, 1980), due to increased peak knee flexion during support (KFSu) (Nicol et al., 1991; (Derrick et al. 2002)(Derrick et al. 2002)(Derrick et al. 2002)(Derrick et al. 2002)Derrick et al., 2002; Kellis and Liassou, 2009). Peak knee flexion during swing (KFSw) also increases during fatigue (Hausswirth et al., 1997). Although peak hip flexion during swing (HFSw) does not change, peak hip extension during swing (HESw) decreases during prolonged running (Elliot and Roberts, 1980). However, kinematic alterations when running under fatigued conditions vary among individuals (Nicol et al., 1991; Siler and Martin, 1991) and between study designs (Williams, 2007).

Although the kinematics of prolonged running has been previously studied, little is known regarding how kinematics may change during an actual marathon. To our knowledge, no one has evaluated kinematic changes between the early and late stage of an over-ground marathon. Additionally, only one group of researchers has compared kinematic changes between fast and slow runners during a prolonged run: Siler and Martin (1991) reported that kinematics for fast and slow runners change similarly during a fatiguing 10-km treadmill run. However, treadmill running in a laboratory setting likely results in kinematics that differs from over-ground racing (McKenna and Riches, 2007; Riley et al., 2008; Nigg et al., 1995; Morin et al., 2009).

The purpose of this study was to evaluate certain running kinematics during early and late stages of an actual marathon, for fast and slow runners. We asked two research questions: (1) Do certain running kinematics change over an actual marathon?, and (2) Do potential kinematic changes differ between fast and slow runners? We hypothesized that certain running kinematics change from the early to late stage of an actual marathon, and that observed kinematic changes would be smaller for fast runners than slow runners.

METHODS

Subjects

Subjects (n=179) were all participants in the 2010 Salt Lake City Deseret News Marathon. Subject selection was based primarily on finish time. Subject finish times ranged from 2:20:47 to 5:30:10. We attempted to select approximately one subject per half minute (finish time). Subjects were excluded if they walked, carried a water bottle or cup, wore a backpack, or exhibited obvious limping, tripping, or falling when passing our cameras' fields of view. Selected subjects were matched using their race bib number and/or clothing between miles 5 (station 1) and 25 (station 2). Approval for this study was obtained from the race executive board and appropriate human subject institution review board prior to data collection.

Data Collection

Three cameras were set up at miles 5 and 25 (Figure 1). Two high-speed digital cameras (Cameras 1 and 2; shutter speed = 1/250 s, frame rate = 120 Hz) were set on tripods side by side, 10 m away from the right side of the race course, at a height of 1 meter. Only one of these cameras recorded at a time. Digital storage space limited each camera to 11.5 minutes of recording at a time. After every 11.5 minute recording, 5minutes were needed to process and download the recorded video to a computer. The second high-speed camera recorded during this 5-minute duration. Five meters of level course were measured and marked with white chalk lines (Figure 1). We ensured that these 5 meters were level using survey equipment. Fields of view for Cameras 1 and 2 were both set to video across the entirety of this 5-m length. A third camera (Camera 3; shutter speed = 1/250 s, frame rate = 60 Hz) was set on a tripod at a height of 1 meter, with a frontal view of the runners. This camera was used to identify and match the runners between miles 5 and 25. A digital clock was placed directly across from Cameras 1 and 2 to show the marathon time and assist with subject selection

Data Analysis

The following kinematic variables were derived from the collected video at miles 5 and 25 using Dartfish 5.5 software (Dartfish, Fribourg, Switzerland): (1) Station speed (SS; average forward velocity through the aforementioned 5-meter length), (2) SL, (3) GT, (4) sagittal-plane knee angle throughout one gait cycle, and (5) sagittal-plane hip angle throughout one gait cycle. For the joint angles, zero degrees represented anatomical position. Hip flexion, hip extension (beyond anatomical position), and knee flexion were indicated by angles that were greater than zero (as these motions increased, the magnitude of angle also increased). The following six dependent variables were examined at miles 5 and 25 for all subjects: (1) SL, (2) GT, (3) KFSu, (4) HFSw, (5) KFSw and (6) HESw.

Statistical Analyses

Related to the first research question, the influence of running from mile 5 to 25 on the six dependent variables was evaluated using two-tailed paired t-tests. The dependent variables were normalized to station speed (SS) and calculated as a ratio of miles 25 to 5. These ratios were then compared to the value of 1 using the aforementioned t-tests. A ratio that was significantly less than 1 indicated that the dependent variable decreased between miles 5 and 25, while a ratio that was greater than 1 indicated that the dependent variable increased between miles 5 and 25.

Related to the second research question, we used a mixed models regression analysis blocking on subjects, with SS as a covariate, to examine a potential interaction between average running speed (across the entire marathon) and between-station (mile 5 to 25) changes for the six kinematic dependent variables in a non-normalized form. This procedure allowed us to determine whether fast runners altered their running kinematics differently than slow runners. Significance levels for all statistical analyses were set to 0.01, due to multiple variables and tests. Because SS had direct correlation with all the dependent variables except KFSu, SS was not used as a covariate for KFSu.

RESULTS

SS decreased from 3.2 ± 0.4 m/s at mile 5 to 2.9 ± 0.5 m/s at mile 25. The non-normalized sample means and standard deviations for each dependent variable are presented in Table 1. Related to the first research question, all dependent variables changed significantly from mile 5 to 25 (Table 2). SL, GT, KFSw, and HFSw increased between miles 5 and 25, while

KFSu and HESw decreased. Related to the second research question, the only kinematic variable that exhibited a significant interaction between miles 5 and 25 was KFSu ($t = 3.19$, $p < 0.002$), which indicated that the fast runners decreased KFSu less than the slow runners at mile 25 when compared to mile 5 (Figure 2). Additionally, the regression analyses related to KFSu were statistically significant at miles 5 ($t = -6.90$, $p < 0.001$) and 25 ($t = -3.88$, $p < 0.001$); although this finding does not directly relate to our research questions, it indicates that fast runners exhibited more KFSu than the slow runners throughout the race (Figure 2 and Table 3).

In summary, the runners demonstrated significant kinematic changes between miles 5 and 25 for all of the observed kinematic variables. The fast runners decreased their KFSu significantly less than the slow runners between miles 5 and 25.

DISCUSSION

The purposes of this study were to (1) evaluate potential changes in running kinematics during an actual marathon and (2) compare these potential changes between fast and slow runners. Although running kinematics has been studied extensively, this was the first observation of running kinematics during early and late stages of an actual marathon. Related to the first research question, all of the observed running kinematics changed significantly between miles 5 and 25 of a marathon, even after adjusting for the speed differences between the early and late stages of the race. Related to the second research question, fast runners exhibited smaller decreases in KFSu than slow runners, between miles 5 and 25 (i.e., the fast runners more consistently maintained KFSu throughout the race, relative to the slow runner); otherwise, the fast runners changed their running kinematics in a way that was similar to the slow runners.

For all runners, SL increased significantly between miles 5 and 25 (Table 2). This finding agrees with the findings of Hunter and Smith (2007), but contradicts the results of

Kyröläinen et al. (2000) and Elliot and Roberts (1980). Based on these previous findings, neither increased nor decreased SL, alone, is likely to alter running economy. In combination with other kinematic changes, discussed in the following paragraphs, increased SL may facilitate optimization of running economy at the late stage of a marathon (Cavanagh and Williams, 1982).

The present results regarding GT concur with previously reported results (Nicol et al., 1991; Derrick et al., 2002; Kellis and Liassou, 2009). In the presence of fatigue, GT increases (Table 2) because of the attenuation of ground reaction forces that are applied to the lower extremities (Mercer et al., 2002). The present kinematic data support the idea that fatigued runners fail to fully utilize the stretch-shortening mechanism (Derrick et al., 2002), especially about the hip and knee joints. This may be related to the fact that the biceps femoris and rectus femoris are the first to fatigue during long-distance running (Hanon and Thépaut-Mathieu, 2005). Muscle fatigue can result in the attenuation of ground reaction forces and increased GT.

Related to the increased GT, decreased KFSu (Figure 2 and Table 2) could be explained by the inverse relationship between leg stiffness and energy cost of running (Dalleau at al., 1998) and/or the change of impulse during support. Because decreased KFSu implies an increase in leg stiffness (McMahon and Cheng, 1990), the energy cost of running therefore decreases (Dalleau at al., 1998). The equation of impulse, $F \times \Delta t = m \times \Delta v$, explains the interaction of an increased GT and a decreased KFSu we observed, where F is the force transferred to the lower extremities during the support phase, Δt is the GT, m is the mass of the runner and Δv is the change of vertical velocity at the center of mass. The measurement of ground reaction forces during an actual marathon, although logistically difficulty, could elucidate the aforementioned speculation.

Data relating to the increased KFSw (Table 2) at the late stage of the race when compared to the early stage of the race in this study may be best explained by the principle of angular inertia ($H = I\omega$, where H is angular momentum, I is the inertia and ω is the angular velocity). Increased KFSw decreases the inertia of the lower extremities about the hip joint and increases angular velocity (Shim et al., 2003). This increased KFSw supports the ease of swing phase and appears to be a more economical running attribute (Hausswirth et al., 1997).

Data in this study showed a 27.9% decrease in HESw and a 7.4% increase in HFSw (Table 2). These changes in hip kinematics could have been caused by increased trunk flexion that has been previously documented during fatigued running (Elliott and Roberts, 1980 and Hausswirth et al., 1997). Because the hip joint angles were measured in reference to the trunk position, increased trunk flexion shifted the hip measurements forward (i.e., more hip flexion and less hip extension during swing) with an overall decrease range of motion about the hip joint. Increased trunk flexion, however, provides better dynamic stability even though it may increase abnormal stress on the lower-extremity joints (Farrokhi et al., 2008) and further fatigue the lower-extremity muscles and increase the risk of injury (Hart et al., 2009).

Kinematic changes we observed between miles 5 and 25 may also be the result of other factors, in addition to the failure of force production among lower-extremity muscles due to fatigue (Hanon and Thépaut-Mathieu, 2005). Decreased neuromuscular activation (Nicol et al., 1991), altered energy substrate utilization, increased demands for body temperature regulation, muscle damage (Kyröläinen et al., 2000), and/or musculotendon structural changes (Tardioli, 2011) could all potentially influence kinematics during a long run. Although these issues are outside the scope of this study, they might be clarified with future research.

Related to our second research question, the present data fit with the findings of Siler and Martin (1991). All runners change their running kinematics similarly, except that the fast runners in this study decreased their KFSu less than the slow runners between miles 5 and 25 (Table 3).

Fast runners also exhibited significantly more KFSu than slow runners throughout the race. We believe this KFSu difference is best explained by the different conditions of the runners on the race day: through genetic differences or differences in training. Fast runners are likely more capable to effectively produce muscular force over a more extended period of time, relative to the slow runners. Additionally, the slow runners in our study ran for a longer period of time: the fastest and slowest subjects finished the marathon at 2:20:47 and 5:30:10, respectively. In speculation, if the fast runners would have been forced to run for another 3 hours, the results from the comparisons between fast and slow runners may have been different.

The present findings imply that runners need not be overly concerned about any kinematics in order to run faster. While KFSu was the only kinematic variable separated the fast runners from the slow runners, focusing on resistance training that would increases in both muscular strength and endurance of the knee extensors may increase KFSu and maintain a more KFSu throughout a marathon.

There were some limitations related to this study. First, some direct lines of sight were blocked by other runners when some of the runners passed by the cameras' fields of view, especially at mile 5. Consequently, we were unable to collect some data that would have otherwise been collected, particularly for some of the fast runners. Second, using the present methods, any change of running kinematics that may have been related to an existing injury or injury acquired during the race could not be evaluated. Third, subjects might run asymmetrically between left and right lower extremities, however, only the right leg was analyzed. For future reference, setting cameras on both sides of the race course could minimize some of these limitations and increase validity.

In conclusion, we observed that, between miles 5 and 25, runners generally demonstrate increased SL, GT, HFSw, and KFSw, and decreased KFSu and HESu. We believe that these changes reflect an attempt from the runners to minimize energy cost and enhance performance generally. In contradiction to our second hypothesis, the observed kinematics generally changed the same (between miles 5 and 25) for the fast and slow runners; however, the fast runners did exhibit a more consistent KFSu throughout the race, relative to the slow runners. This may have been related more to the runners' condition on race day. Runners should focus on resistance training which would be directed toward increases in both muscular strength and endurance of knee extensors. By so doing, KFSu should be increased and be able to be maintained longer throughout the marathon.

REFERENCES

Cavanagh, P. and Williams, K. (1982). The effect of stride length variation on oxygen uptake during distance running. *Medicine & Science in Sports & Exercise* **14,** 30-35.

Dalleau, G., Belli, A., Bourdin, M. and Lacour, J. (1998). The spring-mass model and the energy cost of treadmill running. *European Journal of Applied Physiology & Occupational Physiology* **77(3)**, 257-263.

Derrick, T., Dereu, D. and McLean, S. (2002). Impacts and kinematic adjustments during an exhaustive run. / Impacts et reglage cinematique lors d' une epreuve de course. *Medicine & Science in Sports & Exercise* **34(6),** 998-1002.

Elliott, B. and Roberts, A. (1980). A biomechanical evaluation of the role of fatigue in middle-distance running. *Canadian Journal of Applied Sport Sciences. Journal Canadien Des Sciences Appliquées Au Sport* **5(4),** 203-207.

Hanon, C. and Thépaut-Mathieu, C. (2005). Determination of muscular fatigue in elite runners.

European Journal of Applied Physiology **94**, 118-125.

Hart, J., Kerrigan, D., Fritz, J. and Ingersoll, C. (2009). Jogging kinematics after lumbar paraspinal muscle fatigue. *Journal of Athletic Training* **44(5)**, 475-481.

Hausswirth, C., Bigard, A. and Guezennec, C. (1997). Relationships between running mechanics and energy cost of running at the end of a triathlon and a marathon. *International Journal of Sports Medicine* **18(5)**, 330-339.

Hausswirth, C. and Lehénaff, D. (2001). Physiological demands of running during long distance runs and triathlons. *Sports Medicine* **31(9)**, 679-689.

Hunter, I. and Smith, G. (2007). Preferred and optimal stride frequency, stiffness and economy: changes with fatigue during a 1-h high-intensity run. *European Journal of Applied Physiology* **100**, 653-661.

Kellis, E. and Liassou, C. (2009). The Effect of Selective Muscle Fatigue on Sagittal Lower Limb Kinematics and Muscle Activity During Level Running. *Journal of Orthopedic & Sports Physical Therapy* **39(3),** 210-220.

Kyröläinen, H., Pullinen, T., Candau, R., Avela, J., Huttunen, P. and Komi, P. V. (2000). Effects of marathon running on running economy and kinematics. *European Journal of Applied Physiology* **82(4),** 297-304.

McKenna, M. and Riches, P. (2007). A comparison of sprinting kinematics on two types of treadmill and over-ground. *Scandinavian Journal of Medicines & Science in Sports* **17**, 649-655.

McMahon, T. and Cheng, G. (1990). The mechanics of running: how does stiffness couple with speed? *Journal of Biomechanics* **23(suppl. 1)**, 65-78.

Mercer, J. A., Vance, J., Hreljac, A., & Hamill, J. (2002). Relationship between shock attenuation and stride length during running at different velocities. *Eur J Appl Physiol,* **87**(4-5), 403-408. doi: 10.1007/s00421-002-0646-9

Morin, J., Samozino, P. and Peyrot, N. (2009). Running pattern changes depending on the level of subjects' awareness of the measurements performed: A "sampling effect" in human locomotion experiments? *Gait & Posture* **30**, 507-510.

Nicol, C., Komi, P. and Marconnet, P. (1991). Fatigue effects of marathon running on neuromuscular performance. I. Changes in muscle force and stiffness characteristics. *Scandinavian Journal of Medicines & Science in Sports* **1**, 10-17.

Nigg, B., Cole, G. and Brüggemann, G. (1995). Impact forces during heel-toe running. *Journal of Applied Biomechanics* **11**, 407-432.

Riley, P., Dicharry, J., Franz, J., Croce, U., Wilder, R. and Kerrigan, D. (2008). A kinematics and kinetic comparison of overground and treadmill running. *Medicine & Science in Sports & Exercise* **40(6),** 1093-1100.

Shim, J., Acevedo, O., Kraemer, R., Haltom, R. and Tryniecki, J. (2003). Kinematic changes at intensities proximal to onset of lactate accumulation. *Journal of Sports Medicine and Physical Fitness* **43(3)**, 274-278.

Siler, W. and Martin, P. (1991). Changes in running pattern during a treadmill run to volitional exhaustion: fast versus slower runners. *International Journal of Sport Biomechanics* **7(1),** 12-28.

Tardioli, A. (2011). Structural changes in the Achilles tendon in response to a marathon: ultrasonographically detectable changes immediately and at 2 weeks postmarathon. *2nd Congress of European College of Sport and Exercise Physicians (ECOSEP) 12th*

Scientific Conference, September 9-11, 2010, London. British Journal of Sports Medicine **45(2)**, *e1 doi:10.1136/bjsm.2010.081554.14*

Table 1. The non-normalized means and standard deviations for each kinematic variables at miles 5 and 25. SL = stride length; GT = ground time; HESw = peak hip extension angle during swing; KFSw = peak knee flexion angle during swing; and HFSw = peak hip flexion angle during swing.

Kinematic variables	**Mile 5**	**Mile 25**
SL (m)	2.26 ± 0.30	2.04 ± 0.33
GT (s)	0.29 ± 0.04	0.31 ± 0.04
KFSu (degree)	42.7 ± 4.4	41.2 ± 4.8
HESw (degree)	16.4 ± 6.7	13.4 ± 7.7
KFSw (degree)	94.1 ± 12.1	87.0 ± 11.6
HFSw (degree)	42.0 ± 5.9	39.7 ± 6.6

Table 2. Average ratios of mile 25 to mile 5 for each kinematic variable, normalized to corresponding station speed. The asterisks indicate that the ratio was significantly different from the value 1 (a value greater than 1 represents an increase in that variable after accounting for the station speed). SL = stride length; GT = ground time; HESw = peak hip extension angle during swing; KFSw = peak knee flexion angle during swing; and HFSw = peak hip flexion angle during swing.

Kinematic variables	**Ratio of Mile 25:5 ± SD**	**t**	**p**
SL	*1.013 ± 0.003	4.56	<0.001
GT	*1.131 ± 0.010	13.42	<0.001
KFSu	*0.968 ± 0.007	-4.52	<0.001
HESw	*0.721 ± 0.211	-1.32	<0.001
KFSw	*1.043 ± 0.008	5.74	<0.001
HFSw	*1.074 ± 0.014	5.43	<0.001

Table 3. Regression slopes (kinematic variable × average running speed) and corresponding p values for the dependent variables at miles 5 and 25, and the p-value related to the comparison between the two slopes. The asterisks indicate that the fast runners had greater peak knee flexion at support (KFSu) than the slow runners. The cross indicates that the fast runners decreased their KFSu less than the slow runners between miles 5 and 25. SL = stride length; GT = ground time; HESw = peak hip extension angle during swing; KFSw = peak knee flexion angle during swing; and HFSw = peak hip flexion angle during swing.

	Slope				
Kinematic variables	**Mile 5**	**p value**	**Mile 25**	**p value**	**Slope difference (p value)**
SL	0.013	0.528	0.020	0.340	0.521
GT	-0.005	0.208	-0.007	0.113	0.461
KFSu	2.299	*<0.001	4.085	*<0.001	†<0.002
HESw	0.905	0.480	1.024	0.448	0.887
KFSw	2.853	0.063	1.529	0.341	0.175
HFSw	0.891	0.449	2.228	0.072	0.063

Figure 1. A schematic depicting the arrangement of the three cameras that were set up at miles 5 and 25 in order to evaluate sagittal-plane running kinematics during an actual marathon.

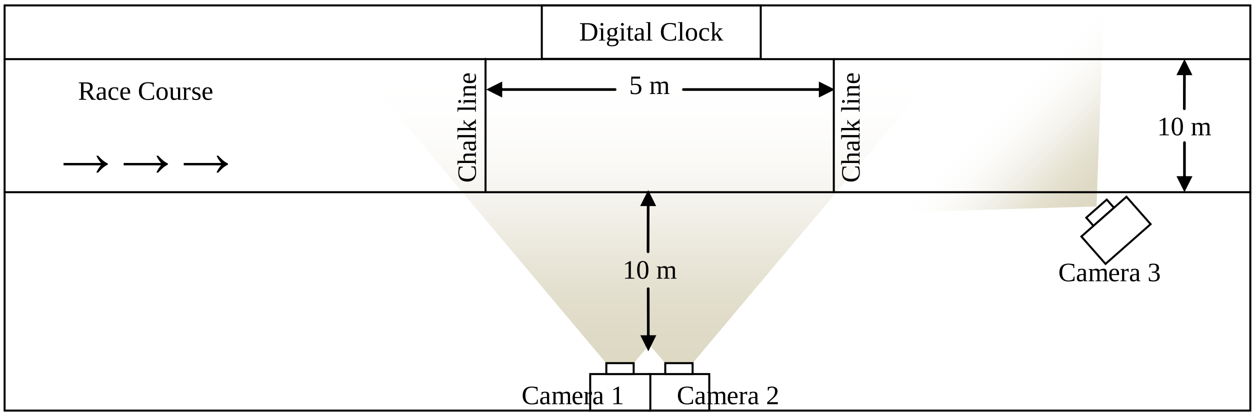
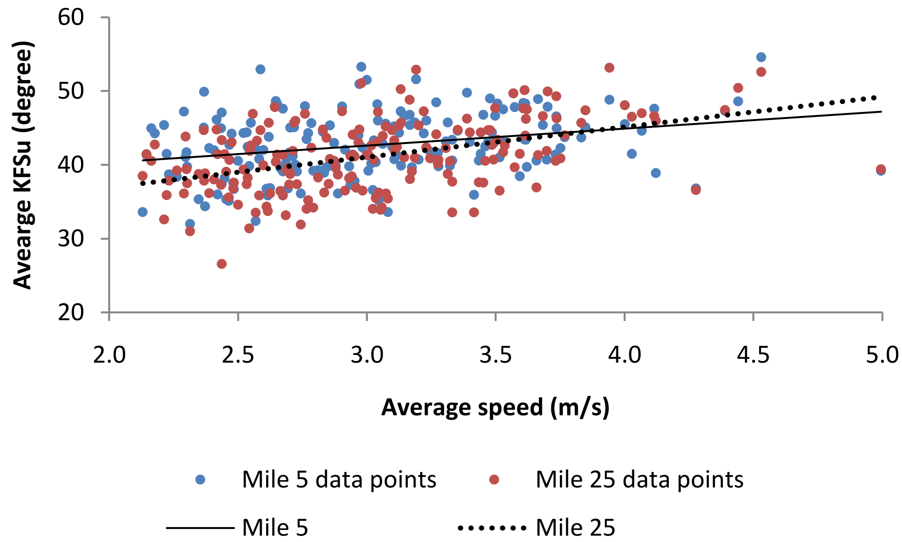


Figure 2. Peak knee flexion during support (KFSu) plotted against average speed (throughout the entire marathon). The fast runners demonstrated significantly greater KFSu than the slow runners at miles 5 ($p<0.001$) and 25 ($p<0.001$). The regression slopes were different between miles 5 and 25, indicating that the fast runners decreased their KFSu less than the slow runners ($p<0.002$) between miles 5 and 25.



Appendix A: Prospectus

CHAPTER ONE: INTRODUCTION

Marathon running is a growing sport. In 2009, the five most well-known marathons in the world—Boston, Chicago, Berlin, London and New York City—had a total of 170,360 finishers. In the USA alone, 397 marathons were recorded in 2009 with nearly 468,000 runners finished. Marathon running involves a challenging distance (26.2 miles) that produces physiological changes; which may lead to alterations in the runners' biomechanics during the race.

The biomechanics of long-distance running have been previously studied. Hunter et al. (2007) reported that runners change their stride length (SL) and stride frequency (SF) throughout a long distance race in order to optimize metabolic cost of running. Kyrolaninen et al. (2000) also studied SL and SF during long distance running, and found that SL decreases while SF increases in order to maintain the pre-set speed on a treadmill. Valiant et al. (1990) found that each five-degree increase of knee flexion during the support phase causes a 25% increase in the metabolic cost of running. Also, Hasegawa et al. (2007) showed that faster marathoners exhibit less ground time than slower marathoners. Gazeau et al. (1997) observed that a more stable running pattern (i.e., less medial-lateral movement of the center of mass) enhances running efficiency, allowing runners to run longer.

Other biomechanical variables change across the duration of a race, depending upon the distance and speed of the runners. Ground time increases slightly over a 3000 m trial run (Elliot et al., 1980). Peak knee flexion during the support phase increases when fatigue onsets (Kellis et al., 2009) because quadriceps muscles are highly activated in a running cycle (Adelaar et al., 1986). Knee flexion during the swing phase decreases (Hausswirth et al., 1997) as hamstring muscles fatigue (Adelaar et al., 1986). Figure 1 illustrates these kinematic descriptions in a running cycle.

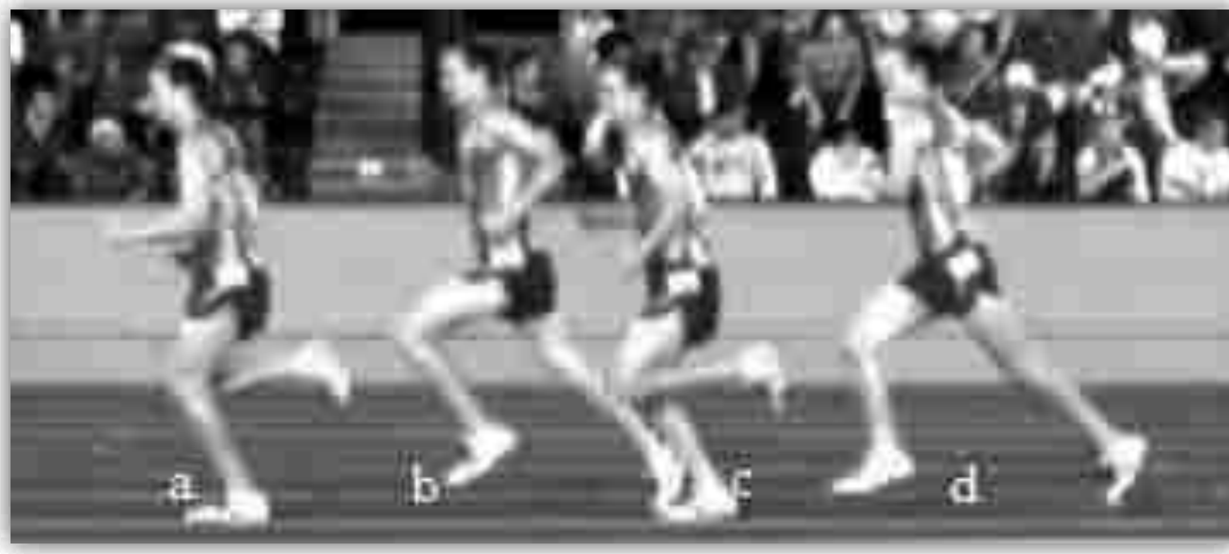


Figure 1. A Running cycle with one full stride. (a) Peak knee flexion during the support phase. (b) Peak hip flexion during the swing phase. (c) Peak knee flexion during the swing phase. (d) Peak hip extension during the early-swing phase.

Although a comprehensive knowledge of the mechanics exhibited by successful marathoners may increase marathon performance, we know little about the biomechanics of fast and slow marathoners during a marathon. Siler et al. (1991) reported that relatively slow runners demonstrate similar kinematic changes, relative to fast runners, during fatigue in a 10-km run. These results may not apply to an actual marathon; particularly since these data were collected on a treadmill in a laboratory setting. Treadmill running may result in kinematics that differ from overground running (e.g., more plantarflexion at impact; Riley et al., 2008; and less push-off; Nigg et al., 1995). As treadmill speed is usually held constant, subjects may adjust their kinematics in order to maintain the speed that is required to stay on the treadmill belt. In reality, runners likely adjust running speed and mechanics when fatigued in an actual race. Therefore, a study investigating kinematic changes during an actual marathon should be conducted.

The purpose of this study is to compare running kinematics between the beginning and end of an actual marathon in fast and slow marathoners. We ask the following research questions: (1) How do leg kinematics change over an actual marathon?, and (2) How do these potential changes differ between the top 10% and bottom 10% marathon finishers?

Hypothesis

We first hypothesize that the leg kinematics are expected to change between the beginning and end of a marathon as described in Table 1.

Kinematic Variables	Direction of change
Stride length	Increase
Stride frequency	Decrease
Ground time	Increase
Peak knee flexion during the support phase	Increase
Peak hip extension during the early swing phase	Increase
Peak knee flexion during the swing phase	Decrease
Peak hip flexion during the swing phase	Decrease

We also hypothesis that the fast runners (fastest 10%) will exhibit smaller kinematic

Table 1. Direction of kinematic changes between the beginning and end of a marathon.

changes than the slow runners (slowest 10%) during a marathon.

Null Hypothesis

Leg kinematics changes are insignificant between the beginning and end of a marathon. And, there is no difference in the leg kinematic changes between the top and bottom 10% of marathon finishers over the course of a marathon.

Operational Definition

Speed: a 5-m mark traveled by the runners divided by the time of travel when passing by the cameras' fields of view

Stride length: displacement between two consecutive heel strikes of the same foot

Stride frequency: number of strides per second

Ground time: time between the initial foot contact and toe-off

Knee joint angle: the knee joint center of the vertex, hip joint center and ankle joint center as end points, calculated at peak knee flexion during the support phase (Figure 2) and peak knee flexion during the swing phase (Figure 3) with the anatomical knee joint position at 180 degrees—any knee flexion results in less than 180 degrees.

Hip joint angle: the hip joint center of the vertex, knee joint center and base of neck as end points, calculated at peak hip flexion during the swing phase (Figure 4) and peak hip extension during the early swing phase (Figure 5) with the anatomical hip joint position at 180 degrees—any hip flexion results in less than 180 degrees and any hip extension results in greater than 180 degrees.

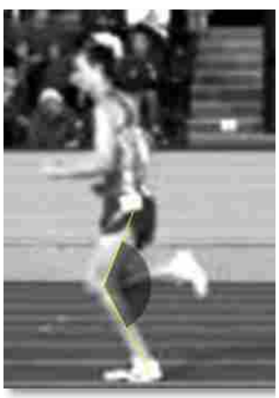


Figure 2. Knee joint angle at peak knee flexion during support phase.

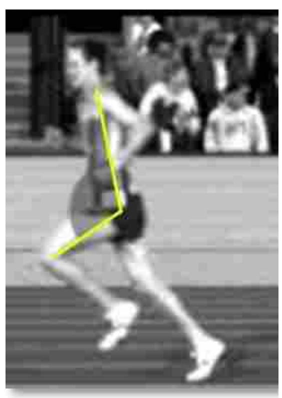


Figure 3. Hip joint angle at peak hip flexion during swing phase.

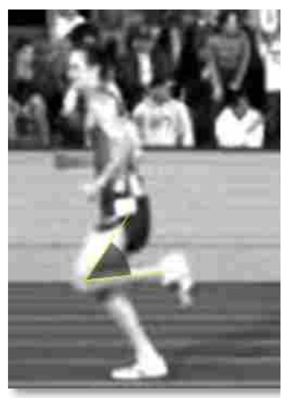


Figure 4. Knee joint angle at peak knee flexion during support phase.

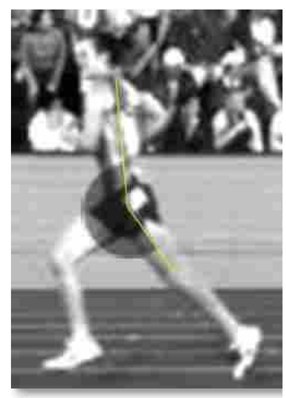


Figure 5. Knee joint angle at peak hip extension during early swing phase.

Delimitations

Subjects are participants in the 2010 Deseret News Marathon, located in Salt Lake City, Salt Lake County, Utah on July 24th in 2010.

Walkers are excluded (i.e., no non-support phase) due to the differences in kinematics between walking and running.

Runners, who carry water bottles or cups on their hands, or camelback on their backs, are also excluded.

Runners with obvious limping, tripping, or falling when passing by the cameras' fields of view are also excluded.

Limitations

Direct line of sight may be blocked by other runners or spectators when runners passing by the cameras' fields of view. Some potential significant data cannot be collected.

Assumptions

We assume that the change of leg kinematics is not compensatory to any existing injury or injury acquired during the race.

We further assume that any change of leg kinematics by the runners is not due to injury.

We also assume that subjects run relatively symmetrical between left and right sides. Cameras are set only on the right side of the course.

In addition, we assume that subjects exhibit their normal form and level of effort for the given phases of the race when passing by the cameras' fields of view.

Significance

Because marathon running is a popular sport, and most marathoners want to know how to improve performance, understanding the kinematic changes during a marathon race will potentially help runners better prepare for the race physiologically and mentally. Coaches and runners may adjust their training programs accordingly to improve certain muscle groups' strength and endurance in order to minimize the kinematic changes and maintain the optimal running pattern throughout the race. Further research will be needed to evaluate the influence of various strength and conditioning interventions on kinematic changes during a marathon.

CHAPTER TWO: REVIEW OF LITERATURE

Introduction

Running is popular because it is simple and inexpensive. In 2009, the five most well-known marathons in the world—Boston, Chicago, Berlin, London and New York City—had a total of 170,360 finishers (Verndale 2009, active.com 2009, running 2009, Marathon 2009, RUNNERS 2009). Marathon running involves a challenging distance in which many physiological changes link to biomechanical alterations. The purpose of this literature review is to explore studies that have shown how biomechanics change during long-distance running and discuss limitations related to the studies. This literature review will first briefly discuss some physiological issues that are involved in a marathon. Physiology is discussed first because it potentially causes the biomechanical changes that will be measured in the current study. Secondly, the relationship between fatigue, running mechanics, and running economy will follow. Thirdly, studies relating strictly to kinematic changes during fatigued running will be reviewed. An especially relevant study, Siler et al. (1991), will be highlighted during this section; these researchers compared fast and slow distance runners during fatigued running. Finally, this review will cover some validity issues that may occur in the past literature.

Physiology

During a 26.2-mile marathon race, many physiological changes occur. Oxygen consumption, energy expenditure, ventilation, and heart rate increase. Conversely, respiratory exchange ratio and true oxygen percent usage decrease; these changes indicate increased utilization of fat as energy substrates. Serum creatine kinase and skeletal troponin I increase, indicating increased muscle damage, and decreased muscular force production and reaction time. Catecholamine levels increase, also indicating a shift of energy utilization from glycogen to fat and increased demand of body thermal regulation (Kyrolaninen et al., 2000). All of the aforementioned physiological changes indicate fatigue. Fatigue likely leads to alteration of biomechanics during long distance running.

Fatigue, Running Mechanics, and Running Economy

Fatigue is an acute motor impairment (Enoka et al., 1992) that is influenced by central and peripheral factors (Meeusen et al., 2006). It has been shown that altering SL, SF, ground time, and foot contact placement while running long distances affect running economy, and thus performance. Hunter et al. (2007) conducted a study on a treadmill with piezoelectric force transducers on 16 subjects, and oxygen uptake was measured. Subjects changed their SL and SF throughout a long distance race in order to optimize their metabolic cost of running while fatigued. Kong et al. (2008) observed six elite Kenyan runners using the Vicon motion analysis system and found that their shorter ground time may improve running economy. During ground time, a braking force is exerted until the center of mass passes over the foot's point of impact. Shorter ground time results in less total braking force. Hasegawa et al. (2007) observed that the majority of marathoners are rear-foot strikers, but more mid-foot strikers are among the fast marathoners than the slow marathoners. They also stated that shorter ground time is related to good running economy. Inversion during foot impact correlates to shorter ground time, and mid-foot strikers are more likely to exhibit inversion during foot impact compared to that among rear-foot strikers. Consequently, they concluded that mid-foot strikers that exhibit increased inversion may have improved running economy. On the contrary, Williams et al. (1987) showed that rear foot strikers with longer ground time, smaller vertical oscillation and more knee extension at foot impact have better running economy when compared to the mid-foot and forefoot strikers. The relationship between running economy and foot inversion may be dependent upon other more significant variables.

Subjects' fatigue tolerance may affect running mechanics, running economy and performance. Siler et al. (1991) observed that some runners are more sensitive to fatigue than others; i.e., some runners performed more poorly than others at the same fatigue level in their study. Kyrolainen et al, (2000) explained that increased muscle damage while running fatigued may reduce running economy due to increased oxygen uptake. The amount of impact of fatigue on both running mechanics and economy has yet to be investigated.

Kinematic Changes During Fatigued Running

Previous researchers have shown that fatigue during a long-distance run alters running mechanics. Derrick et al. (2002) showed that runners increase peak knee flexion and rearfoot inversion during the support phase. Gerlach et al. (2005) demonstrated that the peak impact force magnitude and associated loading rate decrease significantly when running fatigued. On the other hand, the other peak magnitudes were unchanged when SF decreases, and SL increases together with knee flexion during the support phase and ankle dorsiflexion at impact. Hausswirth et al. (1997), however, claimed that SL decreases significantly with increasing knee extension at foot impact and decreasing knee flexion during the swing phase when running at 75% of their maximal aerobic speed (MAS). Kellis et al. (2009) demonstrated that center of pressure location moves posteriorly, knee flexion at toe-off and at foot impact increases, and hip flexion at toe-off increases during fatigued running. Le Bris et al. (2006) showed that runners' kinematics is inconsistent when fatigued; i.e., lack of similarity of crania-caudal movements from one stride to another. Elliot et al. (1980) recorded that runners decrease SL and air time, while increasing SF and ground time; the lower legs become more angled at foot impact, the thighs become less extended prior to toe-off, and the trunk leans more forward. Adelaa et al. (1986) comprehensive analysis of long distance running mechanics explains some reasons why runners change their mechanics when fatigued.

Derrick et al. (2002) conducted a laboratory treadmill experiment on 10 recreational runners, who ran at their 3200-m race pace (3.40 m/s ± 0.38 m/s) to volitional exhaustion. Data were collected at the beginning, middle and end of the run. Accelerometers were attached to the head and legs to measure shock and shock attenuation. Electrogoniometers were attached to the knee and rear-foot to measure joint angles. At foot impact, the knee was flexed 4.4 degrees more, and maximum rear-foot angle was inverted 1.4 degrees more at the end. Such changes lowered the effective mass, which was defined as the portion of the mass accelerated. Runners accelerated faster, and the shock attenuation was higher at the end. These authors suggested that these biomechanical changes when running fatigued could be the bodies' natural instinct to prevent joint injury, or the bodies just could not further maintain the optimal performance. Therefore, they suggested future research to focus on the cause of these kinematic changes.

Gerlach et al. (2005) collected ground reaction force data from 90 female runners on a force-measuring treadmill before and after a modified discontinuous VO2max treadmill protocol. The peak force magnitude and peak loading rate at impact significantly decreased with fatigue, but the peak force at toe-off did not change. These could be explained by the significant decreased SF accompanied by the increased SL. They explained that runners adopt a different running style when fatigued—increase in knee flexion and/or ankle dorsiflexion at foot impact. These changes decrease the effective mass, which was defined by Derrick et al. (2002) to allow faster acceleration and higher shock attenuation. They asked the same questions as Derrick et al.

(2002) did: Do biomechanical changes represent a strategy to prevent injury when running fatigued, or do runners just lose their optimal performance capabilities?

Hausswirth et al. (1997) measured VO2, minute ventilation, heart rate and respiratory exchange ratio data to represent the energy cost of running and used motion analysis for the kinematic changes. Seven male triathletes participated in this treadmill study. Each subject finished three running conditions (1) a 45-minute isolated run at 75% of their MAS—representing their non-fatigued state of running, (2) a 2-hour-15-minute triathlon with a 30-minute swim, a 60-minute bike and a 45-minute run at 75% of their MAS—representing one of the two fatiguing protocols, and (3) a 2-hour-15-minute marathon with a 1-hour-30-minute track run mostly at 80-85% of their maximum heart rate and a 45-minute run on a treadmill at 75% of their MAS—representing the second fatiguing protocol. Only the results that are relevant to our study are summarized here. The marathon run condition resulted in a higher energy cost of running, shorter SL, increased knee extension at foot impact and knee flexion during the swing phase; when compared with the triathlon run. They concluded that these results implied muscle activation changes. The relationship between running economy and biomechanics was complicated. Not one single kinematic variable could explain the decrease in running economy when running fatigued.

Kellis et al. (2009) measured kinematic data and elecromyographic signals of the vastus medialis, gastrocnemius, and biceps femoris muscles of 15 females, running at 3.61 m/s on a treadmill. Measurements were recorded before and after two isolated-muscle fatiguing protocols—knee flexor/extensor and ankle dorsiflexor/plantarflexors—on two separate days. After the ankle-fatigue protocol, decreased dorsiflexion caused foot landing location to be more toward the heel, which lead to greater shock attenuation at impact. Increased knee flexion at toe-off may not have any significance, but subjects had to alter their kinematics to compensate for the ankle fatigue. After the knee-fatigue protocol, the shock attenuation decreased because of an increase in knee flexion at foot impact. Therefore the joints act as a spring to minimize the internal shock to prevent injury. On the other hand, both vastus medialis and gastronemius activities increased after either protocol, which indicated the increase of muscle sensitivity for alpha-gamma coactivation and enhanced stretch reflexes. Such decline in muscle force production might; however, increase the risk of musculoskeletal injury and a decline in performance.

Le Bris et al. (2006) used accelerometers to record certain joint angles on six male sub-elite middle-distance runners on a flat track at their MAS to volitional exhaustion. Stride regularity decreases significantly (i.e., medio-lateral movement increases) by the end of the run. The energy needed to move forward transferred to the stride irregularity. As a result, performance declined when running fatigued. A stable running style without excessive medio-lateral movement throughout the entire race is important.

Elliot et al. (1980) recorded eight runners in a 3000-m time trial on a flat track. They analyzed kinematic changes at the 500-m, 900-m, 1300-m, 2100-m and 2900-m marks. The subjects' goal was to maintain a constant speed throughout the entire run. Decreased SL, accompanied by increased SF, was observed. Also, ground time increased while air-time decreased slightly. The lower leg became more angled at foot impact, which produced a greater deceleration before the center of mass passing the longitudinal axis of the body. The thigh was less extended prior to toe-off and the trunk leaned forward. They recommended coaches to implement specific training to minimize the kinematic changes induced by fatigue.

Adelaa et al. (1986) reviewed different literature about running cycle. At foot impact, the center of mass is decelerated by the gluteus maximus and hamstring musculature while the hip adductors help stabilize the support leg. The quadriceps is the most activated muscles in each running cycle, therefore strength and fatigue tolerance are important for long distance runners. The plantar flexors and peroneals stabilized the plantar surface and hindfoot during the mid-support phase at the highest loading rate. These same foot and ankle muscles also assisted plantar flexion at foot impact and resisted the dorsiflexors at toe-off. These muscles also coordinated the rear-foot inversion and supination of the forefoot with the support of the ligaments, which maintained the integrity of the arch. The plantar flexors were especially important for acceleration. When the gastrosoleus does not function properly; it changes how the center of gravity moves forward during the support phase, dorsi-flexion decreases after foot clearance at toe-off, and thus the activity of the knee flexors increase. The peroneals stabilize ankle during the support phase. They explained how some muscle groups fatigue earlier in a race than others, which caused muscle imbalance and kinematic changes.

In summary, certain mechanical variables are affected by fatigue and change across the duration of a long-distance race. SL decreases, with increased SF, in order to maintain optimal speed (Kyrolaninen et al, 2000). Peak hip flexion during the swing phase (see figure 1) decreases while peak hip extension during the early swing (see figure 2) increases. This is likely due to fatigued hip flexors which fail to produce optimal forces (Siler et al, 1991). Maximum knee flexion during the support phase (see figure 3) increases (Kellis et al, 2009) due to quadricep muscles fatigue; these muscles are activate most in a running cycle (Adelaar et al, 1986). Knee flexion during the swing phase (see figure 4) decreases due to hamstring muscle fatigue; the hamstrings decelerate the forward motion at each foot strike before the center of mass passes the longitudinal axis of the body (Adelaar et al, 1986). Ground time increases (Elliot et al, 1980), probably due to a combination of all of the aforementioned kinematic changes.

Fast versus Slow Runners

Although a comprehensive knowledge of the mechanics exhibited by successful marathoners may increase marathon performance, we know little about the biomechanics of fast marathoners, compared to slow marathoners. Siler et al. (1991) conducted the only study that reported kinematic differences between slow and fast runners. They observed nine fast and 10 slow males running on a treadmill at a pace closest to their most recent 10-km race; the subjects ran to volitional exhaustion. Statistically significant, but small, changes differed between the fast and slow runners for average SL, range of motion at the thigh, maximum thigh flexion, maximum knee extension, maximum knee flexion, and head-neck-trunk segment angle at maximum thigh extension. However, these changes were found to be insignificant when these variables were compared at the same percentage of the total run time (when the subjects reached volitional exhaustion). They concluded that slow runners demonstrated similar kinematic changes relative to fast runners under fatigued conditions.

We found Siler et al. (1991) measurements were inconsistent. As mentioned in the study, small changes in running pattern might be caused by conscious modifications during fatigued running. Almost all of their measurements had extreme contradictory changes. For example, the SL ranged from a 9.0 cm decrease to more than a 34.0 cm increase between the beginning and end of the run. For some subjects, parameters measured at the end were almost the same as at the beginning. Subjects might have consciously tried to maintain their perceived optimal running mechanics because they knew they were being recorded. This highlights one disadvantage of conducting studies in a laboratory setting. Additionally, by including too many dependent variables, the statistics may have been significantly weakened. For example, the observed maximum knee flexion and extension angles were measured but not compared to a fixed plane over the course of the run. The resulting measured range of motion appeared to remain constant and actual changes in flexion and extension were therefore ignored.

Validity of the Past Literature

In addition to subject variability and statistical issues related to the Siler et al. (1991) study, treadmill running likely results in other differences, when compared to overground running. First, treadmill running requires familiarization (Jaskolske et al., 1996). Most subjects may not have the experience of running on a treadmill prior to data collection. Also, treadmill running involves decreased push-off requirements (Riley et al., 2008) and increased plantar flexion at impact (Nigg et al., 1995). Also, importantly, treadmill running involves a constant, predetermined speed regardless of the subjects' condition. Running on a treadmill requires subjects to change their biomechanics to keep pace with the constant moving belt, even when fatigued. In reality, however, when runners fatigue, they likely slow down as well as potentially alter their running mechanics. As mechanical changes are small, these differences between treadmill and overground running are important to consider.

Mechanical changes are dependent upon the running speed. Normalization or statistical adjustment should be employed to eliminate this confounding factor. Siler et al. (1991) did consider the running speed of the subjects and found the significant kinematic differences between fast and slow runners became insignificant. Other studies were conducted on a treadmill; a predetermined constant speed provided an advantage on this issue.

Standardized running shoes could cause unrepresentative mechanics in Derrick et al. (2002) and Kellis et al (2009) studies, compared to the use of shoes subjects normally used. If a subject is not accustomed to the shoes used during the testing protocol, unrepresentative performance may result. For example, among other potential alterations, certain muscles may suffer premature fatigue (Cheung, 2010), and kinematic changes may be altered by the choice to use standardized running shoes. Using different kinds of shoes might increase the variability within a study in Gerlarch et al. (2005), but results may be more applicable to a real race.

Weather conditions also likely affect race performance. Marathon season is normally cooler because hot and humid conditions raise potential risks of dehydration and hyperthermia. Ely et al. (2008) studied performances between slower runners and faster runners in warm weather—slower runners demonstrated a slower overall pace rather than a reduction of speed, exhibited by faster runners. A laboratory normally keeps at a constant temperature and humidity to eliminate these conditions and strengthen the internal validity. However, no official race had ever been done on a treadmill in a laboratory setting (especially a marathon distance).

Because marathon running is a popular sport, and most marathoners want to know how to improve performance. Understanding how kinematic changes differ between fast and slow marathoners during a race will potentially help runners better prepare for the race physiologically and mentally. With the information in this review, we know the direction of certain kinematics change during a marathon. In the current study, we will determine how large the selected kinematic changes are, and how the fast marathoners change their kinematics, relative to the slow marathoners.

CHAPTER THREE: METHODS

Subjects

Two hundred male runners will be selected in the 2010 Deseret News Marathon on July 24, 2010 in Salt Lake City, Utah. Subject selection will be based on the time that each subject passes the 25-mile mark. Beginning with the first subject to pass the 25-mile mark, we will attempt to observe one subject per minute for the next 200 minutes. The selected subjects will then be matched according to subjects' race bib numbers and/or clothing from the 4-mile-mark recording to compare the leg kinematic changes between the beginning and end of the marathon. Approval will be obtained from the race executive board and the appropriate human subject protection committee prior to data collection. Informed consent will not be required as no contact will be made with the subjects.

Data Collection

At mile markers 4 and 25, two high-speed digital cameras (Cameras 1 and 2) will be set on tripods (shutter speed = 1/250 s, frame rate = 120 Hz) side by side, 10 m away from the right side of course, at a height that is perpendicular to the runners' legs (Figure 6). Only one of these high-speed cameras will be running at any given time. Factors related to digital storage space limit each camera to 11.5 minutes of recording at a time. A 15-second break is then needed to process the recording, and a 5-minute break is needed to download the recordings to a computer. The second high-speed camera will record during the aforementioned 15 seconds and 5 minutes.

Five meters of level course will be measured by survey equipment and marked with white chalk lines that will be placed across the entire width of 10-meter-wide course for Dartfish 5.5 (Atlanta, GA, USA) analysis (Figure 6). The two aforementioned cameras' fields of view will be set to video across this 5-m length. A third camera (Camera 3) will be set on a tripod (shutter speed = 1/250 s, frame rate = 60 Hz), at a height of 1 m, with a frontal view of the runners for identification purposes. A digital clock will be placed directly across from Cameras 1 and 2 to show the marathon time; this will facilitate subject selection at each minute of the race.

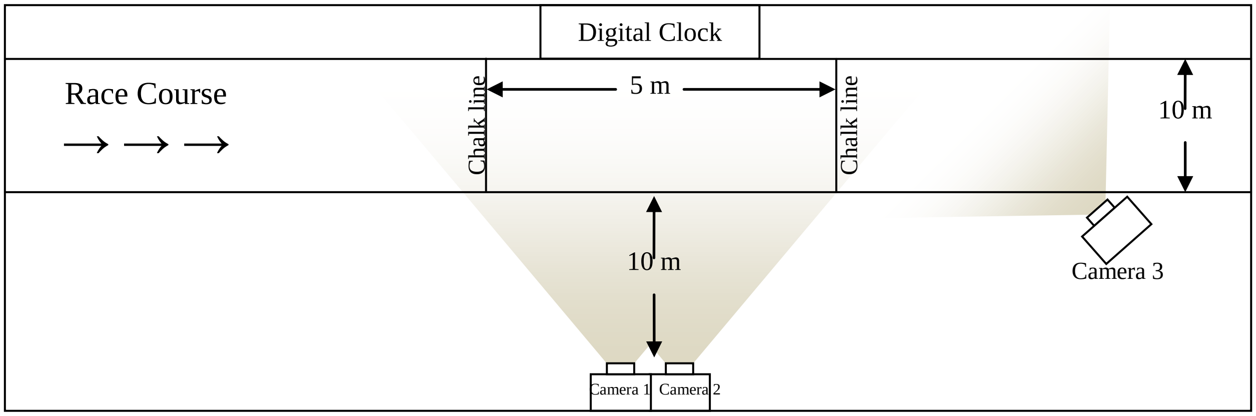


Figure 6. A schematic depicting the camera set up at mile markers 4 and 25.

The independent variable will be the time at which each runner passes the 25-mile mark. The dependent variables for this study will be the difference (between the 4- and 25-mile markers) for the following variables: (1) SL, (2) SF, (3) ground time, (4) peak knee joint flexion angle during the support phase (Figure 2), (5) peak knee joint flexion angle during the swing phase (Figure 3), (6) peak hip joint flexion angle during the swing phase (Figure 4), and (7) peak hip joint extension angle during the early swing phase (Figure 5). These variables will be measured using Dartfish 5.5 (Atlanta, GA). SL (meters per stride) will be calculated as the displacement between two consecutive heel strikes of the same foot. SF (stride per second) will be calculated as 1/(stride time). Ground time will be calculated as the time (s) between the initial foot contact and toe-off. Knee joint angle will be calculated as the orientation between two lines: (1) knee joint center to hip joint center and (2) knee joint center to ankle joint center (the anatomical knee joint angle will equal 180 degrees, and any knee flexion will result in a knee angle that is less than 180 degrees). Hip joint angle will be calculated as the orientation between two lines: (1) knee joint center to hip joint center and (2) hip joint center to the posterior side of the base of the neck. The anatomical hip joint angle will equal 180 degrees, and any hip flexion will result in a hip joint angle that is less than 180 degrees. Hip extension will produce a hip joint angle that is greater than 180 degrees. Each dependent variable, except peak knee flexion during the support phase, will be normalized to the running speed of subject at the time they passed the cameras' fields of view.

Data Analysis

Paired *t* test will be used to compare the change in each dependent variable between the beginning and end of the marathon per individual. Since the seven dependent variable measures per individual are expected to be correlated, a multivariate regression model (   ) will be fit to account for and quantify this correlation in the response structure. The model, which will be fit using SAS, relates   , the changes in each individual's seven dependent variables, to   , the time taken to reach the 25-mile marker. The   vector of coefficients will be analyzed, using Hotelling's   distribution, to determine the nature and strength of the relationship between   and   , providing insight into significant relationships between time to run a marathon and the dependent variables.

REFERENCES

Cheung, R. T. H., & Ng, G. Y. F. (2010). Motion control shoe delays fatigue of shank muscles in runners with overpronating feet. *The American Journal Of Sports Medicine, 38*(3), 486-491.

Derrick, T. R., Dereu, D., & McLean, S. P. (2002). Impacts and kinematic adjustments during an exhaustive run. / Impacts et reglage cinematique lors d ' une epreuve de course. *Medicine & Science in Sports & Exercise, 34*(6), 998-1002.

Elliott, B. C., & Roberts, A. D. (1980). A biomechanical evaluation of the role of fatigue in middle-distance running. *Canadian Journal Of Applied Sport Sciences. Journal Canadien Des Sciences Appliquées Au Sport, 5*(4), 203-207.

Ely, M. R., Martin, D. E., Cheuvront, S. N., & Mountain, S. J. (2008). Effect of ambient temperature on marathon pacing is dependent on runner ability. *Medicine & Science in Sports & Exercise, 40*(9), 1675-1680.

Enoka, R. M., & Stuart, D. G. (1992). Neurobiology of muscle fatigue. *Journal Of Applied Physiology (Bethesda, Md.: 1985), 72*(5), 1631-1648.

Gazeau, F., Koralsztein, J. P., & Billat, V. (1997). Biomechanical events in the time to exhaustion at maximum aerobic speed. *Archives Of Physiology And Biochemistry, 105*(6), 583-590.

Gerlach, K. E., White, S. C., Burton, H. W., Dorn, J. M., Leddy, J. J., & Horvath, P. J. (2005). Kinetic changes with fatigue and relationship to injury in female runners. *Medicine & Science in Sports & Exercise, 37*(4), 657-663.

Hasegawa, H., Yamauchi, T., & Kraemer, W. J. (2007). Foot strike patterns of runners at the 15-km point during an elite-level half marathon. *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.), 21*(3), 888-893.

Hausswirth, C., Bigard, A. X., & Guezennec, C. Y. (1997). Relationships between running mechanics and energy cost of running at the end of a triathlon and a marathon. *International Journal Of Sports Medicine, 18*(5), 330-339.

Hunter, I., & Smith, G. A. (2007). Preferred and optimal stride frequency, stiffness and economy: changes with fatigue during a 1-h high-intensity run. *European Journal Of Applied Physiology, 100*(6), 653-661.

Jaskolski, A., Veenstra, B., Goossens, P., Jaskolska, A., & Skinner, J. S. (1996). Optimal resistance for maximal power during treadmill running. *Sports Med Training Rehab, 7*(1), 17-30.

Kellis, E., & Liassou, C. (2009). The Effect of Selective Muscle Fatigue on Sagittal Lower Limb Kinematics and Muscle Activity During Level Running. *JOURNAL OF ORTHOPAEDIC & SPORTS PHYSICAL THERAPY, 39*(3), 210-220.

Kong, P. W., & de Heer, H. (2008). Anthropometric, gait and strength characteristics of Kenyan distance runners. *Journal of Sports Science & Medicine, 7*(4), 499-504.

Kyröläinen, H., Pullinen, T., Candau, R., Avela, J., Huttunen, P., & Komi, P. V. (2000). Effects of marathon running on running economy and kinematics. *European Journal Of Applied Physiology, 82*(4), 297-304.

Le Bris, R., Billat, V., Auvinet, B., Chaleil, D., Hamard, L., & Barrey, E. (2006). Effect of fatigue on stride pattern continuously measured by an accelerometric gait recorder in middle distance runners. *The Journal Of Sports Medicine And Physical Fitness, 46*(2), 227-231.

Meeusen, R., Watson, P., & Dvorak, J. (2006). The brain and fatigue: new opportunities for nutritional interventions? *Journal of Sports Sciences, 24*(7), 773-782.

Nigg, B. M., De Boer, R. W., & Fisher, V. (1995). A kinematic comparison of overground and treadmill running. *Medicine & Science in Sports & Exercise, 27*(1), 98-105.

Riley, P. O., Dicharry, J., Franz, J., Croce, U. D., Wilder, R. P., & Kerrigan, D. C. (2008). A kinematics and kinetic comparison of overground and treadmill running. *Medicine & Science in Sports & Exercise, 40*(6), 1093-1100.

Siler, W. L., & Martin, P. E. (1991). Changes in running pattern during a treadmill run to volitional exhaustion: fast versus slower runners. / Modifications des parametres biomecaniques de la course lors d'une epreuve maximale sur tapis roulant: comparaison des coureurs rapides et plus lents. *International Journal of Sport Biomechanics, 7*(1), 12-28.

Valiant, G.-A. (1990). Transmission and attenuation of heelstrike accelerations (Transmission et attenuation de l'acceleration a l'impact du talon) *Biomechanics of distance running Human kinetics, Champaign (Illinois) ETATS-UNIS D'AMERIQUE 1990, pp 225-247*.

Williams, K. R., & Cavanagh, P. R. (1987). Relationship between distance running mechanics, running economy, and performance. *Journal Of Applied Physiology (Bethesda, Md.: 1985), 63*(3), 1236-1245.

Appendix B: Raw Data

sub	place	Time	ave_sp	Sp1	Sp2	SL1	SL2	NSL1	NSL2	NSLR	GT1	GT2
1	1	8447	4.995	4.463	4.621	3.130	2.970	0.701	0.643	0.917	0.183	0.208
2	4	9315	4.530	4.666	4.321	2.820	3.140	0.604	0.727	1.202	0.250	0.270
3	5	9503	4.440	4.156	4.142	3.060	2.870	0.736	0.693	0.941	0.250	0.244
4	6	9613	4.389	4.288	3.754	2.970	2.725	0.693	0.726	1.048	0.275	0.313
5	7	9867	4.276	4.417	4.058	3.010	2.760	0.681	0.680	0.998	0.216	0.233
6	8	10238	4.121	3.834	4.142	2.430	2.705	0.634	0.653	1.030	0.220	0.211
7	9	10253	4.115	4.200	3.826	2.850	2.577	0.679	0.673	0.993	0.241	0.255
8	11	10376	4.067	3.991	3.926	2.640	2.543	0.661	0.648	0.980	0.241	0.252
9	13	10475	4.028	4.107	3.575	2.700	2.387	0.657	0.668	1.015	0.212	0.222
10	14	10545	4.001	4.050	3.575	2.620	2.395	0.647	0.670	1.036	0.225	0.258
11	16	10706	3.941	3.733	3.708	2.860	2.780	0.766	0.750	0.979	0.241	0.261
12	17	10965	3.848	3.554	3.802	2.455	2.590	0.691	0.681	0.986	0.277	0.275
13	18	11013	3.831	3.740	3.826	2.480	2.595	0.663	0.678	1.023	0.246	0.250
14	21	11199	3.768	3.778	3.413	2.560	2.395	0.678	0.702	1.036	0.258	0.288
15	22	11247	3.752	3.432	3.413	2.410	2.335	0.702	0.684	0.974	0.241	0.258
16	23	11295	3.736	3.904	2.743	2.720	2.007	0.697	0.732	1.050	0.237	0.302
17	24	11299	3.734	3.652	3.472	2.590	2.375	0.709	0.684	0.964	0.241	0.247
18	25	11305	3.732	3.666	3.575	2.790	2.570	0.761	0.719	0.945	0.216	0.241
19	26	11400	3.701	3.678	3.926	2.770	2.955	0.753	0.753	1.000	0.312	0.283
20	27	11410	3.698	3.723	3.452	2.450	2.275	0.658	0.659	1.001	0.258	0.255
21	28	11457	3.683	3.662	3.619	2.520	2.485	0.688	0.687	0.998	0.246	0.262
22	29	11514	3.665	3.648	3.264	2.640	2.290	0.724	0.702	0.969	0.258	0.277
23	30	11536	3.658	3.687	3.513	2.637	2.550	0.715	0.726	1.015	0.266	0.287
24	32	11654	3.621	3.822	3.065	2.900	2.230	0.759	0.728	0.959	0.250	0.311
25	33	11667	3.617	3.762	3.395	3.060	2.530	0.813	0.745	0.916	0.250	0.294
26	34	11676	3.614	3.728	3.432	2.580	2.495	0.692	0.727	1.051	0.250	0.269
27	35	11684	3.611	3.685	3.575	2.520	2.435	0.684	0.681	0.996	0.283	0.289
28	36	11700	3.606	3.819	3.247	2.420	2.100	0.634	0.647	1.021	0.229	0.262
29	37	11743	3.593	3.513	3.575	2.330	2.435	0.663	0.681	1.027	0.275	0.266
30	39	11806	3.574	3.292	3.575	2.150	2.300	0.653	0.643	0.985	0.262	0.255
31	40	11823	3.569	3.695	3.096	2.500	2.165	0.677	0.699	1.034	0.254	0.283
32	44	11938	3.535	3.585	3.394	2.420	2.370	0.675	0.698	1.035	0.266	0.283
33	45	11957	3.529	3.824	3.128	2.800	2.280	0.732	0.729	0.995	0.250	0.313
34	47	12005	3.515	3.777	3.318	2.460	2.185	0.651	0.658	1.011	0.258	0.283
35	48	12032	3.507	3.510	3.112	2.640	2.420	0.752	0.778	1.034	0.275	0.316
36	49	12063	3.498	3.658	3.685	2.370	2.390	0.648	0.649	1.001	0.266	0.283
37	51	12084	3.492	3.332	3.597	2.300	2.425	0.690	0.674	0.977	0.258	0.250
38	52	12109	3.485	3.684	3.112	2.690	2.310	0.730	0.742	1.016	0.250	0.283
39	53	12131	3.478	3.468	3.034	2.420	2.180	0.698	0.719	1.030	0.283	0.289
40	54	12158	3.471	3.640	3.413	2.750	2.530	0.755	0.741	0.981	0.250	0.275

41	56	12197	3.459	3.493	2.794	2.280	1.840	0.653	0.659	1.009	0.254	0.310
42	57	12225	3.452	3.314	3.356	2.240	2.210	0.676	0.659	0.974	0.275	0.266
43	59	12261	3.441	3.544	3.034	2.440	2.230	0.689	0.735	1.068	0.295	0.338
44	60	12288	3.434	3.554	2.755	2.560	2.120	0.720	0.770	1.068	0.266	0.322
45	64	12352	3.416	3.619	2.944	2.360	1.950	0.652	0.662	1.015	0.248	0.300
46	66	12413	3.399	3.513	2.916	2.375	2.027	0.676	0.695	1.028	0.255	0.291
47	69	12455	3.388	3.412	3.318	2.520	2.440	0.739	0.735	0.996	0.304	0.308
48	76	12587	3.352	3.348	2.988	2.140	2.050	0.639	0.686	1.073	0.275	0.302
49	78	12669	3.331	3.417	3.003	2.520	2.270	0.737	0.756	1.025	0.283	0.322
50	79	12669	3.331	3.773	2.578	2.610	1.900	0.692	0.737	1.065	0.250	0.302
51	82	12699	3.323	3.373	3.145	2.280	2.155	0.676	0.685	1.014	0.283	0.297
52	88	12731	3.314	3.492	2.944	2.555	2.175	0.732	0.739	1.010	0.277	0.291
53	90	12762	3.306	3.290	3.049	2.160	2.045	0.657	0.671	1.022	0.279	0.266
54	95	12871	3.278	3.665	3.128	2.680	2.200	0.731	0.703	0.962	0.246	0.287
55	96	12883	3.275	3.463	3.080	2.410	2.185	0.696	0.709	1.019	0.308	0.316
56	97	12907	3.269	3.582	2.462	2.430	1.795	0.678	0.729	1.075	0.308	0.391
57	106	13002	3.245	3.302	3.034	2.240	2.165	0.678	0.714	1.052	0.287	0.300
58	112	13061	3.231	3.109	2.743	2.120	1.853	0.682	0.676	0.991	0.295	0.347
59	114	13104	3.220	3.282	2.833	2.230	2.065	0.680	0.729	1.073	0.283	0.295
60	119	13183	3.201	3.499	2.755	2.180	1.855	0.623	0.673	1.081	0.283	0.333
61	123	13224	3.191	3.393	3.034	2.260	2.067	0.666	0.681	1.023	0.283	0.316
62	124	13247	3.185	3.385	2.681	2.480	1.987	0.733	0.741	1.011	0.291	0.316
63	126	13294	3.174	3.164	3.432	2.160	2.327	0.683	0.678	0.993	0.283	0.258
64	127	13321	3.168	3.328	2.944	2.300	2.040	0.691	0.693	1.002	0.287	0.294
65	129	13328	3.166	3.283	3.978	2.490	2.900	0.759	0.729	0.961	0.291	0.250
66	136	13420	3.144	3.095	3.640	2.210	2.560	0.714	0.703	0.985	0.291	0.233
67	140	13469	3.133	2.962	3.212	2.120	2.315	0.716	0.721	1.007	0.291	0.266
68	142	13478	3.131	3.452	3.229	2.290	2.165	0.663	0.670	1.011	0.293	0.288
69	145	13501	3.125	3.363	2.694	2.380	1.950	0.708	0.724	1.023	0.287	0.333
70	148	13538	3.117	3.170	2.743	2.290	2.003	0.722	0.730	1.011	0.312	0.327
71	152	13583	3.106	3.212	2.578	2.370	1.970	0.738	0.764	1.036	0.320	0.344
72	155	13586	3.106	3.137	3.264	2.320	2.430	0.740	0.744	1.006	0.327	0.305
73	160	13624	3.097	3.195	2.959	2.400	2.295	0.751	0.776	1.033	0.275	0.261
74	163	13694	3.081	2.959	2.502	2.055	1.833	0.695	0.733	1.055	0.316	0.338
75	164	13728	3.074	3.011	2.743	2.070	1.945	0.688	0.709	1.032	0.324	0.319
76	165	13733	3.073	3.246	2.902	2.010	1.790	0.619	0.617	0.996	0.250	0.277
77	167	13781	3.062	3.318	2.902	2.290	2.095	0.690	0.722	1.046	0.313	0.313
78	170	13802	3.057	3.337	2.930	2.373	2.047	0.711	0.699	0.982	0.277	0.297
79	172	13824	3.052	3.037	3.247	2.115	2.270	0.696	0.699	1.004	0.312	0.305
80	176	13856	3.045	3.325	2.847	2.150	1.873	0.647	0.658	1.018	0.258	0.280
81	178	13869	3.042	3.162	3.264	2.480	2.480	0.784	0.760	0.969	0.325	0.312

82	179	13877	3.041	2.966	2.888	2.130	1.997	0.718	0.691	0.963	0.283	0.280
83	182	13907	3.034	3.575	2.422	2.375	1.700	0.664	0.702	1.057	0.261	0.330
84	184	13941	3.027	3.375	2.647	2.350	1.990	0.696	0.752	1.080	0.295	0.347
85	186	13957	3.023	3.148	2.524	2.220	1.875	0.705	0.743	1.053	0.283	0.311
86	187	13986	3.017	3.108	2.930	2.100	1.930	0.676	0.659	0.975	0.279	0.266
87	190	14041	3.005	3.061	2.795	2.280	2.005	0.745	0.717	0.963	0.329	0.319
88	193	14069	2.999	3.264	3.112	2.575	2.325	0.789	0.747	0.947	0.313	0.336
89	197	14143	2.983	3.413	2.820	2.440	2.040	0.715	0.723	1.012	0.308	0.311
90	201	14169	2.978	3.255	2.730	2.390	2.067	0.734	0.757	1.031	0.262	0.291
91	203	14203	2.971	3.235	2.888	2.460	2.120	0.761	0.734	0.965	0.291	0.308
92	206	14222	2.967	2.874	2.611	1.990	2.120	0.692	0.812	1.172	0.322	0.330
93	210	14264	2.958	3.065	2.681	2.310	1.970	0.754	0.735	0.975	0.287	0.327
94	215	14290	2.953	3.018	2.833	2.010	2.000	0.666	0.706	1.060	0.308	0.305
95	216	14317	2.947	3.501	2.860	2.610	2.165	0.745	0.757	1.016	0.270	0.308
96	217	14330	2.945	3.037	2.730	2.085	1.887	0.686	0.691	1.007	0.304	0.336
97	218	14345	2.941	3.104	2.781	1.960	1.763	0.631	0.634	1.004	0.268	0.289
98	224	14373	2.936	3.374	2.567	2.400	1.810	0.711	0.705	0.991	0.275	0.316
99	226	14397	2.931	2.973	3.018	1.915	1.990	0.644	0.659	1.024	0.304	0.283
100	229	14476	2.915	3.153	2.403	2.270	1.800	0.720	0.749	1.041	0.324	0.380
101	234	14532	2.904	3.072	3.034	2.100	2.030	0.684	0.669	0.979	0.298	0.291
102	241	14611	2.888	3.003	2.422	2.135	1.723	0.711	0.712	1.001	0.311	0.355
103	244	14658	2.879	2.874	2.860	2.010	1.980	0.699	0.692	0.990	0.295	0.297
104	246	14688	2.873	3.195	2.706	2.220	1.900	0.695	0.702	1.011	0.312	0.322
105	248	14769	2.857	3.141	2.916	2.300	2.165	0.732	0.743	1.014	0.312	0.327
106	250	14800	2.851	2.923	2.755	1.870	1.850	0.640	0.672	1.050	0.322	0.322
107	252	14844	2.843	3.065	2.794	2.170	2.045	0.708	0.732	1.034	0.327	0.324
108	254	14887	2.834	3.312	2.794	2.230	1.917	0.673	0.686	1.019	0.283	0.316
109	256	14913	2.829	3.309	2.874	2.285	2.025	0.691	0.705	1.020	0.286	0.280
110	261	15014	2.810	2.944	2.743	1.935	1.787	0.657	0.651	0.991	0.308	0.311
111	272	15115	2.792	3.161	2.567	2.075	1.757	0.656	0.684	1.043	0.295	0.325
112	278	15156	2.784	2.973	2.545	2.230	1.970	0.750	0.774	1.032	0.345	0.341
113	279	15223	2.772	3.206	2.534	2.430	1.953	0.758	0.771	1.017	0.300	0.330
114	282	15258	2.765	3.161	2.365	2.240	1.763	0.709	0.746	1.052	0.345	0.399
115	287	15288	2.760	3.206	2.578	2.220	1.853	0.692	0.719	1.038	0.316	0.347
116	294	15381	2.743	3.161	2.337	2.320	1.773	0.734	0.759	1.034	0.302	0.330
117	297	15466	2.728	2.820	2.781	1.850	1.833	0.656	0.659	1.005	0.313	0.327
118	301	15498	2.723	2.895	2.706	2.080	2.030	0.719	0.750	1.044	0.316	0.319
119	303	15526	2.718	3.180	2.634	2.220	1.793	0.698	0.681	0.975	0.258	0.297
120	307	15553	2.713	3.080	2.346	2.200	1.725	0.714	0.735	1.029	0.283	0.355
121	313	15613	2.703	2.847	2.781	2.010	2.000	0.706	0.719	1.019	0.325	0.330
122	315	15636	2.699	3.049	2.319	2.130	1.650	0.699	0.712	1.018	0.291	0.341

123	316	15662	2.694	2.981	2.681	1.950	1.780	0.654	0.664	1.015	0.287	0.308
124	318	15690	2.689	2.678	2.781	1.890	1.920	0.706	0.690	0.978	0.302	0.313
125	322	15713	2.685	3.365	2.623	2.410	1.880	0.716	0.717	1.001	0.262	0.316
126	324	15781	2.674	2.847	2.545	1.995	1.843	0.701	0.724	1.033	0.283	0.322
127	326	15784	2.673	2.988	2.567	2.080	1.853	0.696	0.722	1.037	0.319	0.354
128	329	15843	2.663	2.934	2.781	1.990	1.877	0.678	0.675	0.995	0.283	0.308
129	335	15913	2.652	2.694	2.670	1.885	1.860	0.700	0.697	0.996	0.313	0.316
130	338	15947	2.646	2.897	2.355	1.950	1.613	0.673	0.685	1.017	0.304	0.347
131	342	15968	2.642	2.640	2.556	1.910	1.853	0.723	0.725	1.002	0.360	0.347
132	348	16083	2.624	2.681	2.768	1.845	1.900	0.688	0.686	0.998	0.345	0.333
133	353	16108	2.620	3.003	2.916	2.140	2.080	0.713	0.713	1.001	0.347	0.313
134	356	16133	2.615	2.667	2.472	2.010	1.793	0.754	0.726	0.963	0.312	0.347
135	358	16164	2.610	2.687	2.412	1.730	1.600	0.644	0.663	1.030	0.320	0.333
136	360	16240	2.598	3.034	2.224	2.290	1.607	0.755	0.722	0.957	0.291	0.352
137	366	16310	2.587	2.941	2.755	2.260	2.060	0.768	0.748	0.973	0.370	0.416
138	370	16345	2.582	2.820	2.482	1.960	1.750	0.695	0.705	1.014	0.316	0.352
139	373	16401	2.573	3.145	2.015	2.240	1.540	0.712	0.764	1.073	0.314	0.410
140	374	16433	2.568	3.247	2.100	2.310	1.590	0.711	0.757	1.064	0.300	0.380
141	376	16505	2.556	2.846	2.432	2.030	1.707	0.713	0.702	0.984	0.322	0.333
142	380	16551	2.549	3.218	2.706	2.290	2.055	0.712	0.760	1.067	0.291	0.322
143	381	16573	2.546	2.902	2.600	2.020	1.830	0.696	0.704	1.011	0.300	0.316
144	382	16592	2.543	2.905	2.502	1.950	1.743	0.671	0.697	1.038	0.312	0.355
145	385	16631	2.537	3.214	2.646	2.210	1.825	0.688	0.690	1.003	0.308	0.347
146	387	16654	2.534	3.019	2.043	2.060	1.497	0.682	0.733	1.073	0.300	0.383
147	393	16740	2.521	2.860	2.233	2.210	1.737	0.773	0.778	1.007	0.350	0.388
148	397	16875	2.500	2.808	2.412	2.190	1.935	0.780	0.802	1.029	0.404	0.444
149	403	16992	2.483	2.712	2.768	2.080	2.150	0.767	0.777	1.013	0.384	0.363
150	406	17008	2.481	2.988	2.545	2.040	1.713	0.683	0.673	0.986	0.325	0.333
151	407	17048	2.475	3.063	2.634	2.020	1.670	0.659	0.634	0.961	0.279	0.308
152	408	17105	2.467	2.533	2.513	1.805	1.750	0.712	0.696	0.977	0.330	0.354
153	409	17129	2.463	2.423	2.658	1.645	1.797	0.679	0.676	0.996	0.297	0.327
154	413	17192	2.454	2.694	2.847	1.885	1.943	0.700	0.683	0.976	0.297	0.299
155	415	17235	2.448	3.051	2.781	2.130	1.970	0.698	0.708	1.015	0.262	0.291
156	418	17314	2.437	2.977	2.442	2.140	1.770	0.719	0.725	1.009	0.316	0.380
157	419	17316	2.437	3.100	2.328	2.160	1.660	0.697	0.713	1.023	0.304	0.358
158	421	17337	2.434	3.096	2.988	2.270	2.060	0.733	0.689	0.940	0.287	0.291
159	425	17434	2.420	2.662	2.176	1.815	1.557	0.682	0.715	1.049	0.336	0.406
160	428	17459	2.417	3.018	1.989	2.120	1.453	0.702	0.731	1.040	0.312	0.402
161	430	17532	2.407	2.906	2.383	2.030	1.843	0.698	0.773	1.107	0.329	0.372
162	435	17671	2.388	3.102	2.768	2.280	1.970	0.735	0.712	0.968	0.320	0.341
163	442	17794	2.371	2.805	2.184	1.905	1.477	0.679	0.676	0.996	0.230	0.269

164	443	17822	2.368	2.865	2.374	1.990	1.583	0.695	0.667	0.960	0.279	0.313
165	445	17829	2.367	2.538	2.442	1.850	1.767	0.729	0.724	0.993	0.341	0.336
166	452	17980	2.347	2.567	2.250	1.955	1.747	0.762	0.776	1.019	0.333	0.352
167	457	18239	2.313	2.334	2.122	1.645	1.517	0.705	0.715	1.014	0.338	0.366
168	460	18327	2.302	2.650	2.422	1.950	1.757	0.736	0.725	0.986	0.375	0.386
169	461	18346	2.300	2.600	2.545	1.927	1.897	0.741	0.745	1.006	0.356	0.372
170	462	18377	2.296	2.658	2.168	1.930	1.647	0.726	0.759	1.046	0.312	0.377
171	464	18426	2.290	2.901	2.374	2.060	1.747	0.710	0.736	1.036	0.325	0.361
172	467	18648	2.263	2.224	2.009	1.610	1.457	0.724	0.725	1.002	0.377	0.383
173	477	18908	2.232	2.435	2.545	1.745	1.787	0.717	0.702	0.980	0.333	0.322
174	479	18978	2.223	2.650	2.422	1.890	1.755	0.713	0.725	1.016	0.329	0.354
175	486	19065	2.213	2.672	2.301	1.945	1.683	0.728	0.731	1.005	0.352	0.369
176	492	19383	2.177	2.473	2.355	1.750	1.647	0.708	0.699	0.988	0.341	0.358
177	495	19509	2.163	2.794	2.502	1.950	1.790	0.698	0.715	1.025	0.291	0.327
178	505	19673	2.145	2.403	2.192	1.780	1.675	0.741	0.764	1.031	0.383	0.422
179	509	19810	2.130	2.623	2.328	1.900	1.760	0.724	0.756	1.044	0.370	0.366

NGT1	NGT2	NGTR	KFSu1	KFSu2	KFSuR	HESw1	HESw2	NHESw1	NHESw2	NHESwR
0.047	0.045	0.966	39.200	39.400	1.005	20.900	35.400	4.683	7.661	1.636
0.058	0.063	1.080	54.600	52.600	0.963	29.600	22.650	6.344	5.242	0.826
0.059	0.059	1.003	48.600	50.433	1.038	27.300	22.300	6.569	5.384	0.820
0.073	0.083	1.142	47.300	47.450	1.003	17.500	8.350	4.082	2.224	0.545
0.053	0.057	1.088	36.800	36.600	0.995	19.800	17.750	4.483	4.374	0.976
0.055	0.051	0.926	38.900	45.933	1.181	15.900	21.900	4.147	5.287	1.275
0.061	0.067	1.098	47.600	46.600	0.979	32.700	24.000	7.785	6.273	0.806
0.063	0.064	1.017	44.600	47.000	1.054	29.400	28.100	7.366	7.158	0.972
0.054	0.062	1.149	41.500	46.500	1.120	24.400	19.000	5.940	5.314	0.895
0.064	0.072	1.133	45.500	48.100	1.057	17.300	13.900	4.271	3.888	0.910
0.070	0.070	1.007	48.800	53.150	1.089	27.200	20.600	7.286	5.556	0.763
0.077	0.072	0.935	45.100	47.400	1.051	17.500	17.100	4.924	4.498	0.913
0.067	0.065	0.978	43.700	45.700	1.046	27.700	20.000	7.406	5.228	0.706
0.076	0.085	1.107	43.750	44.000	1.006	12.500	13.600	3.309	3.985	1.204
0.075	0.076	1.006	42.250	40.900	0.968	12.900	4.300	3.759	1.260	0.335
0.077	0.110	1.423	44.950	46.300	1.030	18.100	21.300	4.636	7.766	1.675
0.068	0.071	1.052	46.550	49.300	1.059	21.850	16.600	5.984	4.781	0.799
0.066	0.067	1.025	41.400	40.550	0.979	30.600	24.900	8.346	6.964	0.834
0.077	0.072	0.937	47.850	49.950	1.044	-5.100	-1.400	-1.387	-0.357	0.257
0.069	0.074	1.078	40.700	41.900	1.029	24.600	22.700	6.608	6.576	0.995
0.072	0.072	1.012	45.400	46.600	1.026	20.350	19.550	5.557	5.403	0.972
0.076	0.085	1.118	48.900	41.300	0.845	28.100	23.000	7.702	7.046	0.915
0.078	0.082	1.049	40.600	36.950	0.910	23.750	21.600	6.442	6.149	0.954
0.081	0.101	1.247	39.700	47.500	1.196	32.000	14.500	8.374	4.731	0.565
0.078	0.087	1.108	43.400	46.200	1.065	25.700	17.100	6.832	5.037	0.737
0.072	0.078	1.086	48.300	43.950	0.910	22.100	24.750	5.928	7.211	1.217
0.078	0.081	1.031	43.450	50.100	1.153	20.150	20.100	5.468	5.622	1.028
0.069	0.081	1.176	48.400	47.650	0.985	20.300	28.400	5.316	8.747	1.645
0.076	0.074	0.982	38.450	41.500	1.079	24.100	22.850	6.861	6.391	0.932
0.078	0.071	0.921	47.800	39.650	0.829	7.400	10.300	2.248	2.881	1.282
0.077	0.091	1.194	49.700	49.700	1.000	21.400	18.600	5.791	6.008	1.037
0.079	0.083	1.056	43.100	42.600	0.988	26.900	15.650	7.504	4.611	0.615
0.082	0.100	1.222	47.500	41.700	0.878	22.800	18.500	5.963	5.914	0.992
0.075	0.085	1.138	41.000	36.500	0.890	15.500	13.600	4.104	4.098	0.999
0.090	0.102	1.128	48.300	43.400	0.899	25.700	27.900	7.323	8.964	1.224
0.077	0.077	0.993	46.650	47.700	1.023	18.100	20.700	4.948	5.617	1.135
0.075	0.069	0.927	42.900	40.700	0.949	24.800	25.000	7.442	6.951	0.934
0.077	0.091	1.184	44.400	42.700	0.962	11.200	13.400	3.040	4.306	1.416
0.083	0.095	1.143	49.000	44.700	0.912	17.300	12.300	4.988	4.055	0.813
0.075	0.080	1.067	43.100	44.700	1.037	19.100	7.600	5.247	2.227	0.424

0.089	0.111	1.250	42.500	40.550	0.954	18.900	13.900	5.411	4.975	0.920
0.080	0.079	0.988	46.800	37.600	0.803	13.050	16.500	3.938	4.917	1.249
0.096	0.112	1.168	41.500	44.400	1.070	12.700	12.750	3.584	4.203	1.173
0.091	0.117	1.290	40.600	37.650	0.927	22.700	13.800	6.387	5.009	0.784
0.083	0.102	1.229	35.950	33.550	0.933	17.500	18.300	4.836	6.215	1.285
0.083	0.100	1.205	43.100	44.400	1.030	30.000	24.500	8.540	8.403	0.984
0.090	0.093	1.028	49.750	46.250	0.930	15.050	9.350	4.411	2.818	0.639
0.090	0.101	1.120	44.600	44.750	1.003	19.800	25.350	5.914	8.483	1.434
0.094	0.107	1.138	43.400	37.700	0.869	20.300	11.700	5.941	3.896	0.656
0.080	0.117	1.464	40.600	33.550	0.826	19.400	7.500	5.142	2.909	0.566
0.088	0.094	1.073	39.900	40.500	1.015	12.400	5.000	3.676	1.590	0.433
0.083	0.099	1.186	45.750	38.750	0.847	20.550	18.800	5.885	6.385	1.085
0.081	0.087	1.079	43.200	42.250	0.978	14.600	22.450	4.438	7.363	1.659
0.078	0.092	1.172	39.800	40.650	1.021	35.800	18.950	9.768	6.058	0.620
0.091	0.103	1.124	41.600	40.150	0.965	7.300	6.350	2.108	2.062	0.978
0.109	0.159	1.455	48.450	44.150	0.911	14.000	2.450	3.908	0.995	0.255
0.091	0.099	1.088	41.800	40.900	0.978	16.200	19.100	4.906	6.296	1.283
0.112	0.126	1.134	46.000	42.350	0.921	13.400	5.900	4.310	2.151	0.499
0.090	0.104	1.158	44.250	47.250	1.068	12.500	11.100	3.809	3.918	1.029
0.095	0.121	1.270	40.700	45.350	1.114	11.200	10.900	3.201	3.956	1.236
0.093	0.104	1.118	51.600	52.900	1.025	5.950	2.750	1.754	0.907	0.517
0.093	0.118	1.262	45.750	40.950	0.895	16.000	23.050	4.727	8.597	1.818
0.082	0.075	0.922	39.650	39.100	0.986	8.800	14.450	2.781	4.210	1.514
0.088	0.100	1.130	45.400	38.050	0.838	28.800	26.600	8.654	9.034	1.044
0.076	0.063	0.825	46.800	48.800	1.043	13.800	22.600	4.204	5.682	1.351
0.075	0.064	0.850	46.600	41.000	0.880	15.000	24.000	4.847	6.593	1.360
0.090	0.083	0.922	39.900	45.700	1.145	18.700	18.850	6.313	5.869	0.930
0.084	0.089	1.069	47.250	50.250	1.063	12.650	8.800	3.664	2.725	0.744
0.099	0.124	1.249	44.350	45.350	1.023	26.600	16.333	7.909	6.064	0.767
0.103	0.119	1.156	41.300	42.400	1.027	12.000	23.250	3.786	8.477	2.239
0.107	0.133	1.246	45.200	43.300	0.958	15.900	5.600	4.950	2.172	0.439
0.097	0.093	0.961	40.750	42.000	1.031	15.450	14.750	4.926	4.518	0.917
0.082	0.088	1.080	42.500	44.700	1.052	16.300	19.000	5.101	6.422	1.259
0.114	0.135	1.182	33.600	35.400	1.054	25.100	13.700	8.483	5.475	0.645
0.106	0.116	1.098	45.300	36.100	0.797	27.100	16.800	9.001	6.126	0.681
0.085	0.096	1.119	45.550	45.200	0.992	11.750	11.050	3.620	3.808	1.052
0.094	0.108	1.144	42.850	43.900	1.025	20.300	15.050	6.117	5.186	0.848
0.089	0.101	1.139	35.933	34.250	0.953	21.450	12.100	6.429	4.130	0.642
0.100	0.094	0.935	35.650	33.900	0.951	12.400	9.300	4.082	2.864	0.702
0.084	0.098	1.168	35.150	36.250	1.031	9.000	10.633	2.706	3.735	1.380
0.099	0.096	0.969	46.000	47.150	1.025	18.000	18.600	5.692	5.698	1.001

0.094	0.097	1.027	48.200	43.150	0.895	23.000	18.300	7.754	6.337	0.817
0.092	0.136	1.476	40.350	35.500	0.880	26.050	17.550	7.286	7.247	0.995
0.103	0.131	1.275	43.300	40.650	0.939	14.000	3.400	4.148	1.284	0.310
0.099	0.123	1.247	36.600	34.050	0.930	12.200	1.700	3.876	0.674	0.174
0.086	0.091	1.061	40.200	42.600	1.060	8.850	15.000	2.847	5.120	1.798
0.104	0.114	1.095	39.200	41.400	1.056	18.400	18.800	6.011	6.726	1.119
0.103	0.108	1.049	51.500	41.300	0.802	11.700	7.900	3.584	2.539	0.708
0.091	0.110	1.210	42.300	36.500	0.863	23.550	16.200	6.900	5.745	0.833
0.089	0.107	1.192	53.300	51.050	0.958	14.900	14.200	4.577	5.201	1.136
0.095	0.107	1.120	50.950	44.800	0.879	21.300	16.000	6.585	5.541	0.841
0.115	0.126	1.101	44.000	43.000	0.977	13.350	7.000	4.645	2.681	0.577
0.107	0.122	1.143	44.200	36.900	0.835	16.400	9.550	5.351	3.562	0.666
0.101	0.108	1.065	37.800	41.150	1.089	15.450	12.350	5.119	4.359	0.851
0.088	0.108	1.224	44.050	41.300	0.938	10.500	4.200	2.999	1.469	0.490
0.111	0.123	1.112	41.400	44.100	1.065	11.150	16.300	3.671	5.970	1.626
0.093	0.104	1.116	38.200	38.450	1.007	18.150	12.750	5.847	4.585	0.784
0.094	0.123	1.315	37.300	41.250	1.106	19.800	11.900	5.868	4.636	0.790
0.095	0.094	0.985	39.800	38.200	0.960	9.700	4.900	3.262	1.624	0.498
0.121	0.158	1.312	42.050	36.500	0.868	13.400	4.000	4.250	1.665	0.392
0.095	0.096	1.013	47.900	47.250	0.986	16.000	23.800	5.208	7.845	1.506
0.118	0.147	1.240	36.100	38.667	1.071	14.950	7.300	4.978	3.014	0.606
0.103	0.104	1.005	39.950	39.600	0.991	10.050	0.350	3.497	0.122	0.035
0.101	0.119	1.181	42.950	40.550	0.944	9.050	8.100	2.832	2.994	1.057
0.104	0.112	1.077	45.350	40.800	0.900	9.300	13.200	2.961	4.527	1.529
0.110	0.117	1.061	39.850	37.400	0.939	15.900	10.900	5.440	3.956	0.727
0.106	0.116	1.097	39.650	43.650	1.101	8.500	8.000	2.774	2.863	1.032
0.095	0.113	1.186	38.950	36.250	0.931	9.200	2.150	2.778	0.770	0.277
0.085	0.097	1.151	44.500	44.800	1.007	20.200	24.300	6.104	8.455	1.385
0.105	0.113	1.074	39.300	38.300	0.975	13.650	15.700	4.636	5.725	1.235
0.103	0.126	1.232	39.200	34.200	0.872	9.500	3.050	3.005	1.188	0.395
0.115	0.134	1.168	45.650	42.300	0.927	13.200	13.200	4.440	5.186	1.168
0.103	0.130	1.265	44.300	35.200	0.795	16.000	14.750	4.991	5.820	1.166
0.126	0.169	1.337	43.500	34.050	0.783	20.300	10.350	6.421	4.377	0.682
0.108	0.135	1.244	47.950	46.900	0.978	19.550	14.500	6.098	5.625	0.922
0.104	0.141	1.353	36.100	31.900	0.884	22.900	9.600	7.244	4.108	0.567
0.116	0.117	1.014	39.100	37.350	0.955	5.550	8.050	1.968	2.895	1.471
0.110	0.118	1.070	40.000	45.950	1.149	11.333	7.200	3.915	2.661	0.680
0.093	0.113	1.207	45.100	45.700	1.013	13.000	11.000	4.088	4.175	1.021
0.115	0.151	1.313	41.200	41.900	1.017	15.900	14.000	5.162	5.967	1.156
0.116	0.119	1.024	45.033	38.750	0.860	11.950	13.150	4.198	4.729	1.127
0.112	0.147	1.315	41.650	37.333	0.896	21.600	8.750	7.085	3.773	0.533

0.103	0.115	1.112	36.800	39.600	1.076	5.833	-0.450	1.957	-0.168	-0.086
0.117	0.113	0.963	40.867	39.200	0.959	8.450	5.500	3.155	1.978	0.627
0.094	0.121	1.283	40.200	33.150	0.825	21.000	14.400	6.240	5.491	0.880
0.113	0.126	1.118	39.100	41.350	1.058	24.000	26.150	8.431	10.275	1.219
0.118	0.138	1.164	47.600	35.850	0.753	9.900	-0.300	3.313	-0.117	-0.035
0.105	0.111	1.055	39.600	36.467	0.921	19.000	12.033	6.476	4.328	0.668
0.117	0.118	1.009	48.267	41.400	0.858	13.600	23.100	5.049	8.653	1.714
0.120	0.147	1.230	48.650	40.400	0.830	20.150	4.750	6.957	2.017	0.290
0.131	0.136	1.033	47.933	47.800	0.997	8.950	4.450	3.390	1.741	0.514
0.124	0.120	0.969	36.833	36.100	0.980	13.500	10.050	5.035	3.631	0.721
0.104	0.107	1.030	43.800	45.700	1.043	15.350	14.850	5.111	5.093	0.996
0.130	0.140	1.079	35.850	33.750	0.941	14.700	42.250	5.512	17.094	3.101
0.124	0.138	1.114	36.750	34.350	0.935	12.500	6.750	4.651	2.798	0.602
0.116	0.158	1.364	42.000	39.950	0.951	14.300	8.667	4.714	3.896	0.827
0.142	0.151	1.067	52.950	44.700	0.844	3.000	2.400	1.020	0.871	0.854
0.125	0.142	1.136	40.800	35.850	0.879	20.300	17.000	7.199	6.849	0.951
0.130	0.203	1.560	42.000	43.250	1.030	11.700	4.400	3.721	2.183	0.587
0.117	0.181	1.546	32.400	33.500	1.034	9.500	4.900	2.926	2.333	0.797
0.117	0.137	1.170	42.250	46.900	1.110	12.950	12.700	4.551	5.223	1.148
0.100	0.119	1.189	45.700	42.600	0.932	17.800	19.100	5.532	7.060	1.276
0.109	0.122	1.116	41.950	41.900	0.999	2.933	5.500	1.011	2.115	2.092
0.122	0.142	1.161	39.850	31.400	0.788	10.600	10.500	3.649	4.196	1.150
0.108	0.131	1.215	42.450	38.250	0.901	16.000	1.800	4.978	0.680	0.137
0.127	0.187	1.477	44.400	37.367	0.842	23.800	15.733	7.885	7.701	0.977
0.136	0.174	1.281	44.300	39.350	0.888	21.200	6.750	7.413	3.023	0.408
0.158	0.184	1.164	40.550	34.600	0.853	13.100	8.050	4.665	3.337	0.715
0.134	0.131	0.980	36.700	37.600	1.025	10.800	9.100	3.983	3.288	0.825
0.111	0.131	1.174	37.550	36.800	0.980	7.500	6.550	2.510	2.574	1.025
0.101	0.117	1.163	44.200	43.033	0.974	13.050	7.500	4.261	2.847	0.668
0.140	0.141	1.008	42.700	40.667	0.952	14.750	9.567	5.822	3.807	0.654
0.135	0.123	0.912	35.100	35.575	1.014	11.200	4.200	4.622	1.580	0.342
0.111	0.105	0.946	35.350	39.050	1.105	15.650	12.000	5.810	4.216	0.726
0.095	0.105	1.097	38.200	41.450	1.085	16.150	11.400	5.293	4.100	0.775
0.128	0.156	1.219	47.100	43.333	0.920	16.900	7.850	5.676	3.215	0.566
0.115	0.154	1.332	37.400	26.567	0.710	22.350	19.300	7.209	8.290	1.150
0.094	0.097	1.036	44.950	37.300	0.830	19.100	12.450	6.169	4.166	0.675
0.152	0.186	1.223	36.000	41.433	1.151	9.200	22.300	3.456	10.248	2.965
0.133	0.202	1.517	46.150	44.800	0.971	12.500	6.000	4.142	3.017	0.728
0.128	0.156	1.219	41.950	38.000	0.906	10.700	2.700	3.681	1.133	0.308
0.110	0.123	1.121	42.250	36.150	0.856	8.750	6.800	2.820	2.457	0.871
0.096	0.123	1.284	34.400	38.850	1.129	18.900	14.967	6.737	6.852	1.017

0.109	0.132	1.207	49.900	37.833	0.758	10.400	5.750	3.630	2.422	0.667
0.132	0.138	1.040	45.050	44.700	0.992	12.850	9.360	5.063	3.834	0.757
0.137	0.157	1.141	35.350	38.767	1.097	19.550	11.967	7.616	5.319	0.698
0.157	0.173	1.100	32.000	31.000	0.969	4.250	0.367	1.821	0.173	0.095
0.146	0.159	1.094	39.750	37.500	0.943	5.850	2.750	2.207	1.136	0.514
0.143	0.146	1.022	41.700	39.400	0.945	12.000	11.000	4.615	4.322	0.937
0.142	0.174	1.226	41.050	43.850	1.068	18.250	22.350	6.867	10.307	1.501
0.124	0.152	1.222	47.200	36.100	0.765	17.800	9.850	6.135	4.149	0.676
0.172	0.191	1.107	38.350	39.250	1.023	9.100	8.050	4.091	4.007	0.980
0.132	0.126	0.957	38.700	37.850	0.978	14.800	17.950	6.078	7.053	1.160
0.134	0.146	1.094	41.500	35.900	0.865	12.350	12.500	4.660	5.162	1.108
0.138	0.160	1.161	45.400	32.600	0.718	8.100	8.950	3.032	3.889	1.283
0.145	0.152	1.050	44.250	42.750	0.966	0.300	-10.350	0.121	-4.394	-36.221
0.117	0.131	1.116	44.950	40.550	0.902	30.650	15.550	10.971	6.214	0.566
0.176	0.192	1.096	41.350	41.450	1.002	10.850	28.050	4.516	12.796	2.833
0.140	0.157	1.127	33.600	38.500	1.146	10.900	8.100	4.156	3.479	0.837

KFSw1	KFSw2	NKFSw1	NKFSw2	NKFSwR	HFSw1	HFSw2	NHFSw1	NHFSw2	NHFSwR
129.600	121.750	29.037	26.349	0.907	46.000	40.000	10.306	8.657	0.840
116.400	113.850	24.947	26.349	1.056	42.800	43.050	9.173	9.963	1.086
112.700	109.000	27.118	26.314	0.970	51.300	41.350	12.344	9.983	0.809
92.900	91.650	21.667	24.413	1.127	51.200	44.433	11.942	11.836	0.991
107.500	95.700	24.338	23.581	0.969	41.500	37.100	9.395	9.142	0.973
113.300	117.200	29.550	28.294	0.957	44.300	46.267	11.554	11.170	0.967
109.700	104.800	26.117	27.392	1.049	42.000	32.900	9.999	8.599	0.860
105.900	89.500	26.533	22.799	0.859	38.400	37.500	9.621	9.553	0.993
119.500	109.700	29.094	30.682	1.055	35.400	34.800	8.619	9.733	1.129
111.450	101.800	27.518	28.473	1.035	44.000	42.800	10.864	11.971	1.102
122.500	119.600	32.813	32.257	0.983	44.200	48.100	11.840	12.973	1.096
104.350	108.900	29.363	28.643	0.975	49.450	49.100	13.915	12.914	0.928
112.000	114.700	29.945	29.980	1.001	42.500	44.200	11.363	11.553	1.017
112.400	99.100	29.755	29.038	0.976	53.400	46.900	14.136	13.742	0.972
90.800	102.000	26.456	29.887	1.130	43.150	42.100	12.572	12.336	0.981
112.200	89.200	28.741	32.524	1.132	42.000	32.500	10.758	11.850	1.101
101.100	94.600	27.686	27.247	0.984	34.800	34.900	9.530	10.052	1.055
110.000	102.200	30.003	28.584	0.953	36.400	36.900	9.928	10.321	1.040
90.800	115.200	24.685	29.346	1.189	52.300	54.300	14.219	13.832	0.973
97.550	100.700	26.204	29.170	1.113	38.400	28.600	10.315	8.285	0.803
106.100	113.250	28.971	31.296	1.080	38.350	28.400	10.472	7.848	0.749
98.600	92.900	27.026	28.459	1.053	38.200	38.250	10.471	11.717	1.119
104.300	96.000	28.292	27.329	0.966	41.500	45.950	11.257	13.081	1.162
115.650	87.800	30.263	28.649	0.947	41.600	34.300	10.886	11.192	1.028
117.950	92.550	31.353	27.262	0.869	51.000	42.750	13.557	12.592	0.929
120.000	112.800	32.186	32.866	1.021	48.300	47.250	12.955	13.767	1.063
96.700	88.350	26.240	24.711	0.942	42.150	38.300	11.438	10.712	0.937
114.550	93.100	29.998	28.673	0.956	46.300	41.300	12.125	12.720	1.049
84.500	81.900	24.056	22.907	0.952	33.550	32.800	9.551	9.174	0.961
99.900	97.850	30.342	27.368	0.902	44.200	31.600	13.425	8.838	0.658
119.000	98.300	32.202	31.751	0.986	37.000	32.450	10.012	10.481	1.047
90.200	85.200	25.161	25.105	0.998	45.650	39.750	12.734	11.713	0.920
104.300	97.400	27.277	31.135	1.141	37.500	33.200	9.807	10.613	1.082
90.200	83.700	23.882	25.223	1.056	44.200	42.050	11.703	12.672	1.083
122.050	107.200	34.776	34.444	0.990	45.900	46.150	13.078	14.828	1.134
91.500	92.600	25.012	25.128	1.005	43.100	37.750	11.782	10.244	0.869
99.000	97.750	29.710	27.179	0.915	33.700	34.100	10.113	9.481	0.938
99.800	89.200	27.091	28.661	1.058	47.000	42.000	12.758	13.495	1.058
100.450	91.550	28.962	30.179	1.042	46.400	46.700	13.378	15.394	1.151
113.900	96.050	31.288	28.144	0.900	39.800	37.050	10.933	10.856	0.993

102.800	85.400	29.429	30.568	1.039	45.900	33.500	13.140	11.991	0.913
99.000	95.000	29.875	28.310	0.948	44.300	39.550	13.368	11.786	0.882
96.000	89.450	27.092	29.486	1.088	49.000	50.200	13.828	16.548	1.197
112.600	92.250	31.684	33.484	1.057	37.150	30.500	10.454	11.071	1.059
85.800	75.150	23.711	25.523	1.076	45.100	38.250	12.463	12.990	1.042
95.500	84.350	27.187	28.929	1.064	38.200	24.500	10.875	8.403	0.773
98.900	96.400	28.984	29.050	1.002	38.200	36.750	11.195	11.075	0.989
92.600	87.000	27.657	29.113	1.053	41.800	32.750	12.484	10.959	0.878
107.750	92.700	31.532	30.868	0.979	52.400	48.800	15.335	16.250	1.060
110.200	87.433	29.210	33.918	1.161	39.900	33.050	10.576	12.821	1.212
93.100	85.100	27.600	27.063	0.981	44.950	41.950	13.326	13.341	1.001
105.000	94.600	30.070	32.128	1.068	52.750	41.800	15.106	14.196	0.940
94.300	89.200	28.666	29.257	1.021	36.350	42.250	11.050	13.858	1.254
120.000	77.700	32.743	24.838	0.759	37.800	30.050	10.314	9.606	0.931
95.400	86.050	27.550	27.936	1.014	45.250	39.200	13.067	12.726	0.974
85.000	77.900	23.727	31.646	1.334	46.000	38.450	12.841	15.620	1.216
89.850	84.850	27.211	27.970	1.028	35.800	33.750	10.842	11.125	1.026
86.150	78.850	27.706	28.750	1.038	48.550	47.650	15.614	17.374	1.113
100.500	97.000	30.624	34.236	1.118	40.900	38.100	12.463	13.447	1.079
88.950	75.100	25.425	27.259	1.072	38.650	41.750	11.047	15.154	1.372
87.200	78.550	25.702	25.893	1.007	41.900	47.000	12.350	15.493	1.255
110.500	96.400	32.648	35.953	1.101	39.500	32.050	11.671	11.953	1.024
82.650	89.300	26.122	26.019	0.996	41.850	34.900	13.227	10.169	0.769
94.700	85.500	28.457	29.038	1.020	27.600	23.400	8.294	7.947	0.958
95.500	106.550	29.093	26.786	0.921	41.500	41.700	12.642	10.483	0.829
93.800	109.500	30.308	30.080	0.992	44.450	42.850	14.362	11.771	0.820
95.700	108.300	32.306	33.717	1.044	47.850	51.200	16.153	15.940	0.987
89.650	94.800	25.969	29.358	1.130	46.850	48.300	13.571	14.958	1.102
93.050	81.750	27.666	30.350	1.097	31.700	33.300	9.425	12.363	1.312
85.500	74.700	26.975	27.237	1.010	42.800	36.050	13.503	13.145	0.973
102.800	88.750	32.004	34.428	1.076	40.200	45.300	12.515	17.573	1.404
94.950	101.500	30.271	31.093	1.027	46.450	44.500	14.809	13.632	0.921
117.200	108.850	36.681	36.788	1.003	37.400	37.000	11.705	12.505	1.068
82.067	78.000	27.736	31.169	1.124	26.000	31.700	8.787	12.667	1.442
99.067	87.400	32.904	31.868	0.969	41.900	44.700	13.916	16.299	1.171
86.400	79.350	26.617	27.345	1.027	32.800	27.200	10.105	9.373	0.928
96.000	94.000	28.929	32.393	1.120	41.600	41.300	12.536	14.232	1.135
99.100	82.600	29.700	28.193	0.949	36.500	37.550	10.939	12.816	1.172
84.600	85.850	27.853	26.440	0.949	41.250	39.250	13.581	12.088	0.890
97.400	87.400	29.290	30.703	1.048	38.850	38.450	11.683	13.507	1.156
96.800	103.500	30.611	31.706	1.036	53.100	48.400	16.792	14.827	0.883

96.500	96.200	32.533	33.315	1.024	43.300	41.400	14.598	14.337	0.982
90.900	74.300	25.424	30.680	1.207	29.500	31.950	8.251	13.193	1.599
98.050	85.800	29.050	32.410	1.116	45.050	43.350	13.347	16.375	1.227
96.400	80.550	30.627	31.919	1.042	40.600	34.300	12.899	13.592	1.054
91.400	89.000	29.407	30.377	1.033	42.200	47.400	13.577	16.178	1.192
90.200	87.200	29.468	31.199	1.059	40.350	34.050	13.182	12.183	0.924
109.300	93.200	33.483	29.950	0.895	44.500	48.600	13.632	15.618	1.146
110.150	92.250	32.275	32.716	1.014	47.600	39.650	13.947	14.062	1.008
106.300	91.050	32.654	33.349	1.021	44.800	43.850	13.762	16.061	1.167
97.050	89.400	30.003	30.960	1.032	35.900	36.100	11.099	12.502	1.126
102.300	88.900	35.596	34.043	0.956	38.500	46.150	13.396	17.672	1.319
96.500	84.100	31.488	31.365	0.996	43.000	32.550	14.031	12.140	0.865
79.700	74.500	26.408	26.294	0.996	49.900	48.350	16.534	17.065	1.032
99.800	84.000	28.503	29.371	1.030	43.800	38.500	12.509	13.462	1.076
89.100	81.900	29.337	29.997	1.023	42.000	41.150	13.829	15.072	1.090
88.100	76.100	28.382	27.368	0.964	32.200	43.450	10.373	15.626	1.506
90.500	76.150	26.820	29.666	1.106	43.800	43.200	12.980	16.829	1.297
78.850	84.500	26.519	27.998	1.056	42.550	46.800	14.311	15.507	1.084
91.700	78.500	29.084	32.673	1.123	40.700	39.900	12.909	16.607	1.287
92.100	91.400	29.978	30.129	1.005	41.100	38.500	13.378	12.691	0.949
85.950	73.650	28.620	30.412	1.063	39.550	34.000	13.170	14.039	1.066
86.300	83.700	30.028	29.266	0.975	45.250	49.300	15.745	17.238	1.095
81.800	75.200	25.601	27.795	1.086	45.650	44.900	14.287	16.596	1.162
90.000	84.800	28.658	29.083	1.015	38.900	38.000	12.387	13.033	1.052
83.800	81.950	28.669	29.746	1.038	47.200	44.700	16.148	16.225	1.005
88.600	83.400	28.910	29.852	1.033	47.700	46.600	15.564	16.680	1.072
95.150	84.100	28.727	30.102	1.048	48.600	50.100	14.673	17.933	1.222
106.600	104.150	32.214	36.239	1.125	43.000	37.300	12.994	12.979	0.999
83.250	83.850	28.273	30.573	1.081	36.900	38.500	12.532	14.038	1.120
95.950	89.300	30.351	34.789	1.146	50.250	48.250	15.895	18.797	1.183
73.250	90.333	24.636	35.493	1.441	44.900	44.550	15.101	17.504	1.159
93.500	83.200	29.164	32.827	1.126	40.300	38.500	12.570	15.191	1.208
92.950	79.750	29.402	33.727	1.147	53.300	49.200	16.860	20.807	1.234
81.950	83.800	25.561	32.508	1.272	42.550	43.100	13.272	16.720	1.260
83.300	71.750	26.349	30.701	1.165	20.000	28.100	6.326	12.024	1.901
90.800	87.100	32.201	31.324	0.973	45.100	47.867	15.994	17.214	1.076
94.300	102.100	32.577	37.737	1.158	46.733	39.950	16.144	14.766	0.915
101.400	74.700	31.890	28.355	0.889	50.200	37.100	15.788	14.083	0.892
92.150	73.950	29.919	31.517	1.053	39.800	43.550	12.922	18.561	1.436
81.050	79.900	28.473	28.734	1.009	41.333	44.900	14.520	16.147	1.112
113.650	92.250	37.277	39.782	1.067	45.900	44.100	15.055	19.018	1.263

75.350	73.250	25.278	27.319	1.081	43.150	39.700	14.476	14.806	1.023
78.600	84.450	29.347	30.371	1.035	41.400	39.500	15.458	14.205	0.919
101.300	79.700	30.102	30.389	1.010	33.800	35.100	10.044	13.383	1.332
82.350	80.650	28.929	31.689	1.095	39.400	42.100	13.841	16.542	1.195
88.950	83.800	29.765	32.646	1.097	50.950	48.700	17.049	18.972	1.113
86.500	81.650	29.484	29.364	0.996	30.950	36.400	10.549	13.091	1.241
82.500	82.850	30.629	31.036	1.013	42.100	45.200	15.630	16.932	1.083
94.250	79.950	32.539	33.943	1.043	52.550	47.800	18.142	20.294	1.119
82.950	78.950	31.417	30.891	0.983	51.033	51.450	19.328	20.131	1.042
75.000	73.450	27.972	26.536	0.949	48.433	48.550	18.063	17.540	0.971
91.900	93.200	30.601	31.964	1.045	47.500	43.250	15.817	14.833	0.938
82.700	55.200	31.012	22.333	0.720	31.300	47.700	11.737	19.299	1.644
77.000	70.200	28.652	29.103	1.016	38.050	40.300	14.159	16.707	1.180
108.650	88.167	35.815	39.635	1.107	38.333	32.800	12.636	14.745	1.167
90.800	80.900	30.875	29.365	0.951	48.700	47.350	16.560	17.187	1.038
76.200	72.800	27.022	29.331	1.085	43.250	40.450	15.337	16.297	1.063
89.000	72.000	28.303	35.723	1.262	46.800	39.600	14.883	19.648	1.320
76.900	74.100	23.684	35.283	1.490	39.400	32.267	12.135	15.364	1.266
89.250	84.100	31.362	34.584	1.103	37.750	35.200	13.265	14.475	1.091
76.400	74.700	23.743	27.610	1.163	43.100	36.950	13.395	13.657	1.020
87.250	87.200	30.067	33.535	1.115	51.150	59.500	17.627	22.883	1.298
74.000	73.500	25.473	29.371	1.153	40.500	26.900	13.942	10.749	0.771
92.250	79.000	28.701	29.858	1.040	49.850	49.200	15.509	18.595	1.199
90.350	77.500	29.932	37.934	1.267	39.300	41.600	13.020	20.362	1.564
83.100	75.100	29.056	33.634	1.158	42.150	39.400	14.738	17.645	1.197
81.300	78.300	28.949	32.461	1.121	48.000	45.250	17.092	18.759	1.098
81.600	85.050	30.091	30.727	1.021	41.400	37.400	15.267	13.512	0.885
88.500	79.050	29.615	31.060	1.049	45.650	45.750	15.276	17.976	1.177
98.750	85.367	32.240	32.404	1.005	48.750	31.800	15.916	12.071	0.758
80.850	74.367	31.914	29.591	0.927	43.450	41.567	17.151	16.540	0.964
78.100	82.200	32.231	30.928	0.960	31.350	40.467	12.938	15.225	1.177
88.967	81.600	33.030	28.666	0.868	30.333	12.200	11.261	4.286	0.381
92.350	72.067	30.268	25.917	0.856	40.050	37.900	13.127	13.630	1.038
96.500	84.500	32.412	34.610	1.068	42.700	41.633	14.342	17.052	1.189
89.450	70.033	28.852	30.082	1.043	40.700	31.900	13.128	13.702	1.044
103.150	92.200	33.318	30.853	0.926	44.500	35.167	14.374	11.768	0.819
74.800	71.500	28.097	32.856	1.169	38.350	33.533	14.405	15.410	1.070
82.367	75.133	27.291	37.777	1.384	48.850	41.133	16.186	20.682	1.278
78.500	79.700	27.009	33.439	1.238	47.150	39.600	16.223	16.615	1.024
91.800	84.900	29.590	30.672	1.037	45.150	38.800	14.553	14.018	0.963
99.050	78.900	35.308	36.123	1.023	32.400	25.850	11.549	11.835	1.025

80.600	75.950	28.129	31.991	1.137	42.550	29.400	14.850	12.384	0.834
88.550	83.400	34.890	34.159	0.979	42.850	39.133	16.884	16.028	0.949
79.300	77.350	30.893	34.383	1.113	31.300	32.800	12.194	14.580	1.196
77.950	71.900	33.395	33.876	1.014	39.200	33.700	16.794	15.878	0.945
84.850	74.450	32.018	30.742	0.960	42.850	42.100	16.169	17.384	1.075
88.500	83.550	34.035	32.828	0.965	27.300	29.700	10.499	11.670	1.111
86.600	78.900	32.583	36.387	1.117	31.100	35.667	11.701	16.449	1.406
91.600	77.850	31.571	32.791	1.039	39.500	39.350	13.614	16.575	1.217
74.000	73.500	33.267	36.589	1.100	37.800	42.400	16.993	21.107	1.242
75.650	75.250	31.068	29.567	0.952	37.867	39.950	15.551	15.697	1.009
76.100	73.800	28.716	30.474	1.061	33.450	35.200	12.622	14.535	1.152
82.850	73.900	31.011	32.112	1.036	43.900	35.300	16.432	15.339	0.933
75.700	72.200	30.611	30.653	1.001	46.367	46.250	18.750	19.635	1.047
87.100	81.250	31.176	32.468	1.041	34.150	35.050	12.223	14.006	1.146
79.150	85.000	32.945	38.776	1.177	37.250	42.600	15.505	19.434	1.253
84.500	78.700	32.219	33.805	1.049	42.100	35.500	16.052	15.249	0.950