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Performance Accomodation to Midsole Hardness During Running

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PERFORMANCE ACCOMMODATION TO MIDSOLE HARDNESS DURING RUNNING

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SUMMARY

The effects of shoe hardness on impact force characteristics during running were evaluated using both a group and single subject analysis approach. It was hypothesized that non-significant shoe effects previously reported could have resulted from the experimental design and analysis procedures employed. The present study evaluated 18 runners using a single subject procedure in addition to a group design (Shoe Condition X (Subject X Shoe Hardness)). ANOVA analyses identified significant differences ($p < 0.05$) between mean impact forces for the soft shoe condition and mean maximum knee flexion angles for the hard shoe condition. Individual subject analyses identified no significant ($p < 0.05$) impact force differences for eight subjects while 10 subjects exhibited significant differences. A significant correlation coefficient of -0.59 between impact force and maximum knee flexion suggested that some accommodation took place on average but the extent varied among subjects. Post-hoc group analyses identified a relationship ($r = 0.59$) between impact tester results and impact forces for one subgroup of subjects. The results support the hypothesis that subjects can and do respond differently to the same perturbation and that these differential responses can compromise group analysis results.

KEY WORDS:
midsole hardness
performance accommodation
running

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INTRODUCTION

Impact forces have been implicated as a major cause of running injuries (James, Bates and Osternig, 1978; Perry, 1983; Nigg, 1985; van Mechelen, 1992). Protection of the body from excessive impact forces is a primary function of sport shoes (Bates, James, Osternig and Sawhill, 1983; Nigg and Segesser, 1992). Two methods that have been identified for evaluating the shock attenuating properties of various sport shoe designs include:

1. impact tests using impact testing equipment (Clarke, Frederick and Cooper, 1983; Frederick, Clarke and Hamill, 1984; Snel, Dellerman, Heerkens and van Ingen Schenau, 1985; Hennig, Milani and Lafortune, 1993), and
2. evaluation of subjects running across a force platform (Bates et al, 1983; Clarke et al, 1983; Snel et al, 1985; Luethi, Denoth, Kaelin, Stacoff and Stuessi, 1987; Nigg, Bahlsen, Luethi and Stokes, 1987; Hennig et al, 1993).

The in-vitro impact testing methods have been able to distinguish between various midsole cushioning properties, however, when impact test results have been correlated with in-vivo results obtained from

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ground reaction force or accelerometer data, a lack of correlation or relationship has been observed (Clarke et al, 1983; Kaelin, Denoth, Stacoff and Stuessi, 1985; Snel et al, 1985; Nigg et al, 1987; Hennig et al, 1993). This lack of correlation has generally been attributed to kinematic adjustments brought about by adaptation mechanisms (Clarke et al, 1983; Kaelin et al, 1985; Nigg et al, 1987). This lack of relationship is contradictory to considerable anecdotal evidence in the medical/sports medicine profession which suggests that improper footwear can cause injury and that a shoe change can in fact facilitate the healing process in some instances (James et al, 1978; Becker, 1989; McKenzie, Clement and Taunton, 1985; James and Jones, 1990).

Bates and colleagues (1989, 1992) suggested that a lack of statistical power (experimental design) resulting from excessive performer variability in conjunction with too few subjects or trials per subject-condition relative to mean differences between conditions could result in false support for the null hypothesis (no observed differences). Another potential explanation has to do with subject performances. Subjects responding differentially to shoe conditions, i.e. using different performance strategies, threaten external validity (Campbell and Stanley, 1963) which can result in minimal or no observed condition effects.

The effect of performer strategies on group designs has been demonstrated by several researchers. Dufek, Bates, Davis and Malone (1991) reported unique subject responses to different shoes that were masked in the group analysis. In other studies that investigated change of direction movements on rearfoot motion, Simpson and colleagues (1992, 1993) reported that subjects exhibited individual adaptations to the environmental constraints and could not be viewed as a homogeneous group. These results are consistent with Newell's (1985) suggestion that individual subject responses should be investigated when the environment is manipulated. This approach (within subject) is capable of identifying which individuals were affected (and how) by the treatment or condition but lacks generalizability.

Generalizability on the other hand is considered an important advantage of group designs. It is common knowledge, however, that 50% ofthe individual responses within the group fall below the mean value. All individuals do not necessarily respond favorably to a treatment and in fact some may even respond unfavorably. If the group

is our primary concern and the individual is irrelevant then this approach might be acceptable. In many instances, however, an awareness of who was affected, how, and how much are important questions especially as they relate to injury mechanisms and elite performance. An alternative approach in these instances, therefore, is to use a single subject design or both a group and single subject design simultaneously to gain additional insight into subject performances and still maintain the potential for generalizability.

The purpose of the study was to investigate the effects of individual response patterns on the results obtained from a more traditional and commonly accepted group analysis approach. This purpose was accomplished by examining the individual response patterns used to accommodate to midsole hardness during running. It was hypothesized that subjects would respond differentially to changes in shoe hardness based upon their prior experiences and that the individual responses would compromise group analysis results. To accomplish the purpose both a single subject and group analysis design were implemented simultaneously.

METHODS

In order to achieve the purpose, the experimental design used was a shoe condition by subjects nested in shoe hardness (Shoe Condition X (Subject X Shoe Hardness)) (Keppel, 1991, pp. 367-388). A univariate ANOVA approach was selected since only two dependent variables were being evaluated and the primary interest was in the effects of shoe hardness and not some underlying construct on these variables (Hubeith & Morris, 1989). In order to accomplish single subject analyses with sufficient statistical power, 25 trials per shoe condition were required (Bates, Dufek and Davis, 1992; Dufek et al, 1991). This requirement eliminated a totally repeated measures design (and a multivariate approach) which would have required a minimum of 150 trials (6 conditions x 25 trials/condition) for each subject. Based upon our past research experience, achieving this number of trials (150) within a single test session is not possible due to subject fatigue and boredom. Testing across days also is not practical due to excessive performer variability relative to the expected treatment effects (DeVita and Bates, 1987; Bates, Simpson and Panzer, 1987). Based upon these considerations, the design used was considered the most appropriate.

TABLE 1: Mean ground reaction impact force (GRIF), impact tester (IT) and knee angle (MKF) values for within block shoe conditions (soft, medium and hard) and post hoc subgroups (SIG and NS).

	GRIF (N/Kg)		IT (gs)[a]		MKF (deg)	
	Soft	Hard	Soft	Hard	Soft	Hard
Soft	18.33	19.64+	15.99	16.23	46.5	47.0
n = 6	(2.42)	(3.20)			(6.6)	(7.2)
Medium	18.30	19.04	17.08	18.49	44.4	44.3
n = 6	(1.43)	(2.11)			(4.3)	(3.5)
Hard	18.56	19.49	20.69	22.31	45.0	46.2+
n = 6	(3.45)	(3.96)			(7.9)	(7.3)
All	18.39	(19.39)*	17.92	19.01	45.3	45.8*
n = 18	(2.42)	(3.00)			(6.1)	(6.0)
SIG	18.90	20.56*	17.62	18.51	44.9	45.4
n = 10	(2.44)	(2.96)			(6.0)	(6.4)
NS	17.76	17.93	18.30	19.64	45.7	46.4
n = 8	(2.39)	(2.50)			(6.7)	(5.9)

a - no standard deviations for IT results were available using manufacturer's software
** - significantly different ($p<0.05$) condition main effect*
+ - significantly different ($p<0.05$) hardness simple main effect
n - number of subjects in group/condition

The factors of shoe hardness and shoe condition were determined from rearfoot impact characteristics. Six production shoes from several manufacturers were selected and evaluated using an Impact Testing System (Exeter Research Inc.). The test procedure included 25 preimpacts with a mass of 8.5 kg dropped from a height of 0.05 m followed by 20 impact trials. ASTM recommended procedures were followed except the number of trials was increased (from 10 to 20) to improve data reliability and validity. The shoes were then ranked based upon the impact testing results. Since the shoes were production shoes and not custom made, the mean impact force differences between the six shoes were not equal. The average difference between adjacent ranking shoes was 1.26 ±0.75 g. Based upon these test results, shoes were assigned to the shoe condition and shoe hardness factors. The two softest shoes were identified as the soft shoe condition. The next two shoes in hardness were classified as the medium shoe condition with the final two designated as the hard shoe condition. The shoes within each condition were categorized as soft or hard based upon the same tests. The impact test results are given in Table 1.

Eighteen healthy male recreational runners (20 - 37 years of age) volunteered as subjects for the study. Each subject provided informed consent prior to the testing session in accordance with University of Oregon Protection of Human Subjects Committee policy. Testing sessions for each subject consisted of recording 25 successful trials per condition for each of the two shoe conditions. The procedures have been previously described in greater detail (DeVita and Bates, 1988). Subjects were allowed to run in each pair of shoes prior to testing until they felt comfortable running in the shoes. A self selected running speed was then identified for each subject using a timing light system and this speed was maintained (± 5%) for both shoe hardness conditions. An alternative approach could have been to fix speed but this could have resulted in subjects performing in a less natural way. Since the nested design with shoe hardness as a repeated measure for each subject controls for speed on that factor and the other factor (shoe condition) was less important, the self selected pace was considered the better choice.

Right sagittal plane kinematic data of the lower extremity were collected using a NAC high-speed video camera (200Hz) interfaced to a real-time Motion Analysis System. Reflective markers were placed on the hip, knee and ankle joint centers to monitor sagittal plane knee

joint motion. The retro-reflective images were obtained and translated to planar coordinates using a Motion Analysis VP320 video-processor interfaced to an IBM compatible computer. The coordinates obtained were then scaled and the paths smoothed on line using an interactive computer program in conjunction with a Butterworth Low-Pass Filter. Cut-off frequencies (16 to 20 Hz) were selected by the operator based upon visual inspection of the data. The same individual smoothed all paths to ensure consistency in the process. From these coordinates, leg and thigh position were identified and used to calculate maximum knee joint flexion angle (MKF). MKF was selected over knee angle at contact since it has been shown to be a good indicator of performance adjustments and knee stiffness (Greene and McMahon, 1979; McMahon and Greene, 1979; McMahon, Valiant and Frederick, 1987; Dufek and Bates, 1990).

In addition to the kinematic data, simultaneous ground reaction force data were collected using an AMTI force platform (1000 Hz) mounted in the middle of a 25 m runway. The ground reaction force data were synchronized with the video data using an external manual switch that initiated data collection. Only the first maximum vertical ground reaction impact force (GRIF) was identified and quantified for analysis.

Since the study was designed to gain further understanding of individual response patterns and their effect on group analysis results, a combined group and single subject approach was used. The group design used was an ANOVA shoe condition (soft, medium and hard) by subjects nested in shoe hardness (soft and hard). Each of the shoe condition blocks consisted of six subjects for a total of 18 subjects across all three blocks. Subjects within blocks performed 25 successful trials for each of the two shoe hardnesses nested in the block (shoe condition). Initially the interaction of shoe condition by shoe hardness was tested followed by evaluation of the two main effects ($p < 0.05$). Due to the potential for differential subject responses as hypothesized, simple effect planned comparisons were also conducted for the three shoe conditions at the two levels of shoe hardness. The dependent variables evaluated were the GRIF and MKF. The planned comparisons were also evaluated at the $p < 0.05$ level (Keppel, 1991). The group analyses were followed by single subject analyses using a Model Statistics technique (Dufek et al, 1991; Bates et al, 1992) on the same dependent variables (GRIF and MKF). Traditional repeated measures

designs (for groups) are not appropriate for single-subject experiments since the between condition trials are not correlated. The Model Statistics technique was developed to take advantage of the repeated measures concept associated with within-subject experiments rather than use an independent technique that lacks comparison sensitivity.

On the assumption that the single subject analyses would produce both statistically significant and non-significant GRIF responses to the shoe hardnesses, the next step in the analysis was to regroup the subjects based upon these results into two distinct groups for subsequent analyses. This second group evaluation employed a series of repeated measures ANOVA (Subjects X Hardness) analyses on the dependent variables for each of the two groups ($p < 0.05$). Finally, a series of Pearson product moment correlation coefficients were computed for the dependent variables using the original group of 18 subjects and the two subgroups identified using the single subject analyses.

RESULTS

Mean ground reaction impact force (GRIF), impact tester (IT) and maximum knee joint flexion angle (MKF) group values (SDs in parentheses) for all within block (Soft and Hard) shoe conditions are presented in Table 1. The ANOVA analyses (Condition X (Hardness X Subject)) resulted in no significant interactions between the two factors for the two dependent variables (GRIF and MKF). Similar results of no significant differences were observed for the main effects of shoe condition (means not given in Table), however, the main effect of shoe hardness was significantly different for both variables with the harder condition producing the greater values in both cases (18.39 versus 19.39 N/kg for GRIF and 45.3 versus 45.8 degrees for MKF). The simple effect planned comparisons resulted in no significant differences among shoe conditions and a single significant difference for each variable between hardness. The GRIF values differed for the soft condition (18.23 versus 19.64 N/kg) while the MKF values differed for the hard condition (45.0 versus 46.2 degrees) with both variables producing greater values for the harder within block shoe condition.

Mean individual subject values for the GRIF and MKF are presented in Table 2. Ten (55.6%) of the subjects exhibited significantly greater GRIF values for the harder shoe. The remaining eight subjects

TABLE 2: Twenty five trial mean ground reaction impact force (GRIF) and knee angle values for individual subjects.

		GRIF (N/kg)		MKF (degrees)	
Condition	Subject	Soft	Hard	Soft	Hard
Soft	S1	14.28	14.26	51.3	52.4*
	S2	19.19	20.02*	46.8	47.8*
	S3	19.95	22.26*	46.3	46.4
	S4	19.07	21.92*	47.4	46.2
	S5	16.66	17.45*	53.1	54.9*
	S6	20.82	21.93*	34.1	34.2
Medium	S7	17.38	17.63	48.6	47.4*
	S8	17.51	17.36	38.7	39.9
	S9	18.32	19.40*	40.8	41.0
	S10	20.69	22.06	45.0	45.6
	S11	16.76	16.87	49.8	48.6*
	S12	19.12	20.91*	43.7	43.4
Hard	S13	22.49	23.19*	37.7	39.1*
	S14	19.93	24.27*	47.0	47.3
	S15	15.51	16.10	55.3	55.3
	S16	21.24	20.77	41.1	43.7*
	S17	13.49	14.23*	52.6	53.9*
	S18	18.69	18.38	36.2	37.9*

Within block impact tester (IT) values were constant and are presented in Table 1
** - significantly different ($p<0.05$) within subject hardness values*

FIGURE 1: Scatterplot for ground reaction force (GRIF) vs knee angle (MKF) values for the two post hoc subgroups (SIG and NS).

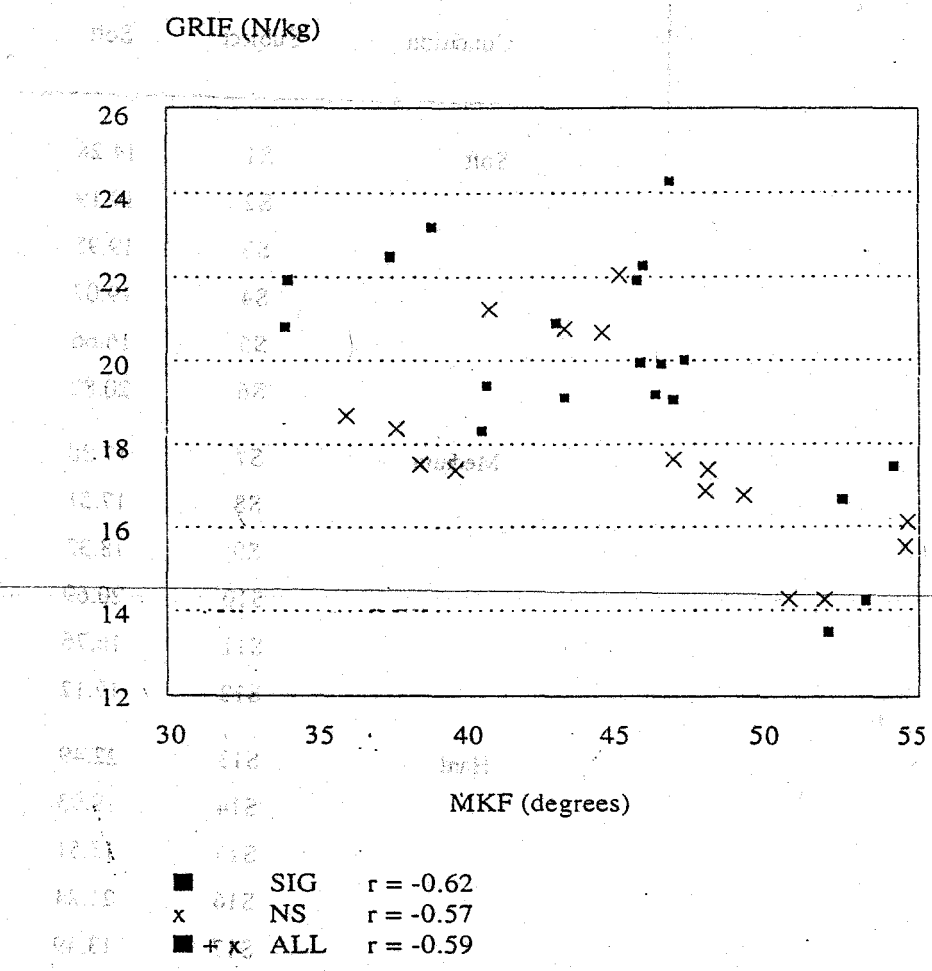
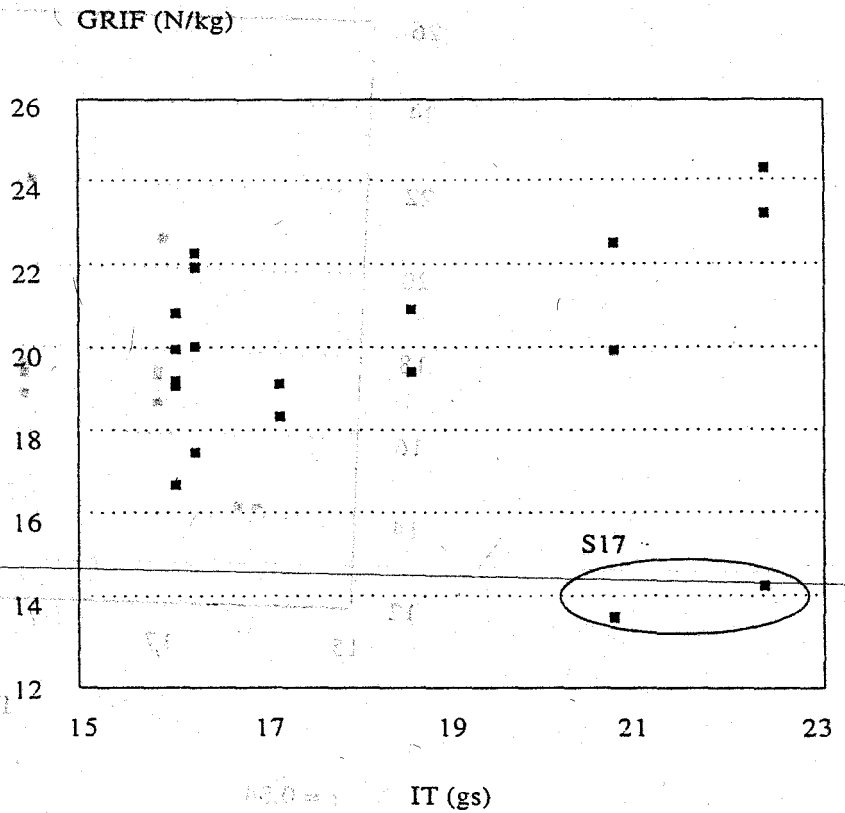


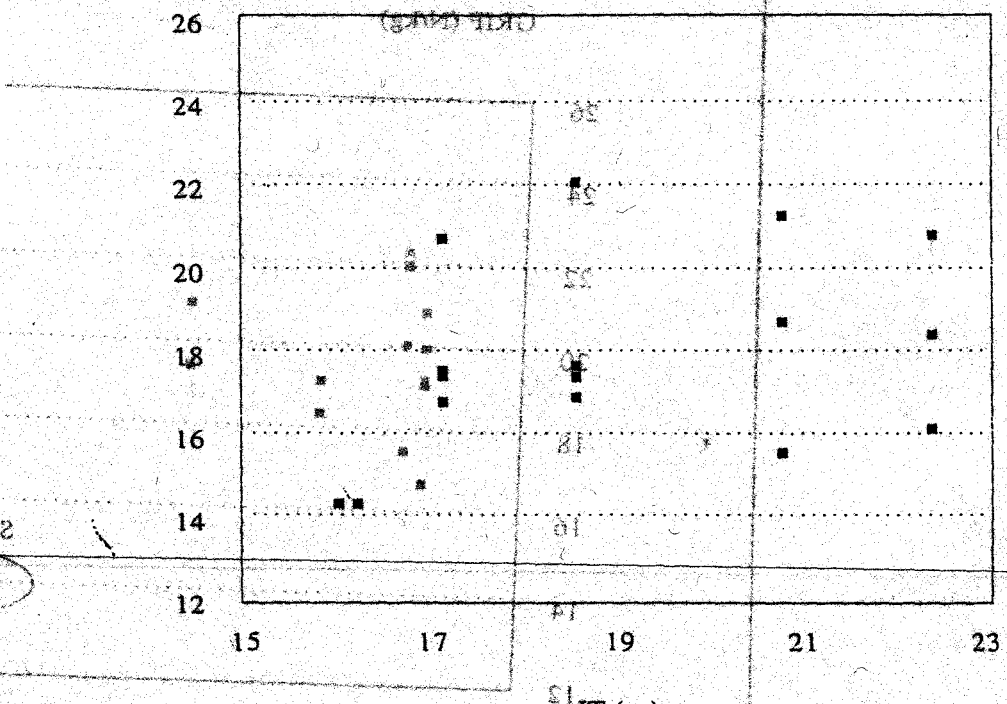
FIGURE 2: Scatterplot for ground reaction force (GRIF) vs impact tester values for the two post hoc subgroups:

Figure 2a: SIG



r = 0.01
r = 0.59 (w/o S17)

Figure 2b: NS



produced non-significant effects with the greater values being evenly distributed between the soft and hard shoe conditions. MKF analyses resulted in nine (50.0%) significant differences with no apparent trend relative to the GRIF results. The results of the GRIF analyses were used to regroup the 18 subjects for further post hoc group analyses into two subgroups comprised of subjects exhibiting significant (SIG) and non significant (NS) responses.

Mean GRIF and MKF values by shoe hardness for the two subgroups (SIG and NS) along with the IT values are given in Table 1. These post hoc groups were analyzed using a one factor repeated measures ANOVA (Hardness X Subject). The GRIF analyses produced the obvious results of a significant difference between the softer and harder values for the SIG group and no differences for the NS group. The MKF analyses resulted in no significant differences for either group although there was a trend toward greater knee flexion angles for the harder shoes in both cases.

Scatterplots between GRIF and MKF and GRIF and IT for all subjects as well as the SIG and NS subgroups are presented in Figures 1 and 2. Since all GRIF vs MKF coefficients were significantly different from zero and similar, the scatterplots are combined (see Figure 1). All three correlations resulted in modest inverse relationships of $r = -0.62$, -0.57 and -0.59 for the SIG, NS and combined groups, respectively. As can be observed from the plots it is apparent, however, that these values are inflated somewhat by the heterogeneity of values within groups.

The scatterplots for GRIF vs IT are given in Figures 2a and 2b for the SIG and NS groups, respectively. The correlation coefficient for the total group was a non-significant 0.06. The NS group produced a non-significant r value of 0.34. The r value for the SIG group was 0.01, however, that value was strongly influenced by the pair of outlier values for S17 in the hard shoe condition group (lower right in scatterplot). The r value without the outliers was a significant 0.59. Similar to the MKF results, these values were also affected by the heterogeneity of values within groups.

DISCUSSION

Several studies have reported no effects of midsole hardness on impact force (Clarke et al, 1983; Kaelin et al, 1985; Snel et al, 1985; Nigg et al, 1987; Hennig et al, 1993). This lack of relationship has been attributed to an adaptation mechanism (Clarke et al, 1983; Kaelin et al, 1985; Nigg et al, 1987). This suggestion that subjects can and will always adapt their performances using some force minimization function is contradictory to injury data indicating that improper footwear can be a cause of impact related injuries (James et al, 1978; McKenzie et al, 1985; Becker, 1989; James and Jones, 1990). The present study was directed toward explaining these seemingly contradictory results.

It has been previously suggested that individual subject performance differences can compromise group analysis results (Bates et al, 1979; Dufek et al, 1991; Dufek, Bates, Stergiou and James, 1995). The results from the present study partially support this suggestion. The nested ANOVA analysis results for the GRIF values indicated a main effect response between shoe hardness in the absence of a significant interaction which suggests similar responses within the three shoe condition blocks (soft, medium and hard). The planned comparisons, however, identified only one significant response (soft) indicating that the subjects in the medium and hard shoe condition groups adapted to the within condition hardnesses. In addition, there were no observed differences between the three shoe conditions suggesting that all three groups of subjects accommodated among shoe conditions. However, since different subjects were evaluated in the three different shoe conditions the similar GRIF values could have been the result of accommodation and/or different subject performance characteristics.

The single subject analyses provided additional insight into the general performance characteristics relative to the GRIF variable. Ten subjects exhibited significant responses which were distributed among the three shoe conditions with five, two and three occurring in the soft, medium and hard conditions, respectively. All significant results were in the expected direction with the hard shoe producing greater values than the soft shoe. The eight non-significant responses were evenly distributed in both directions. The distribution of significant and nonsignificant individual responses along with the directions and

magnitudes of these responses at least partially explain the outcome of the group analysis. The significant response distributions among the three shoe conditions also indicate that subjects were less likely to change their performance strategy (adapt) for shoes having the best cushioning properties although this outcome was also observed for selected (but fewer) subjects in the other two shoe conditions. From these results it does not appear that adaptation within the temporal constraints of this type of experiment is a consistent and universal mechanism used by individuals as suggested by other researchers (Clarke et al, 1983; Kaelin et al, 1985; Nigg et al, 1987). It is certainly possible that adaptation might occur over a longer period of time but this premise was not evaluated in the present study nor by the previous researchers.

The lack of significant differences observed by other researchers certainly could have been the result of adaptation on the part of all or the majority of subjects tested. An alternative explanation for the lack of differences could also be a lack of statistical power. Bates (1989) estimated the power values for one previous study (Nigg et al, 1987) based upon the data presented to be only about 25% indicating the low probability of finding differences even if they did exist. For the present study, power estimates using the model presented by Bates et al (1992) indicated approximate values of 75 - 100% and 70% for the group ($n = 8$, 10 and 18) and single subject analyses, respectively, for identifying mean GRIF differences of approximately 1.0 N/kg. Corresponding values for detecting mean differences of 1.5 N/kg were 98 - 100% and 92%. These statistical power values indicate a high probability of detecting real differences of the magnitudes indicated. Detecting differences of 1.0 N/kg in the present study using three or fewer trials per subject-condition would have resulted in approximate group and single subject power values of 227% and 14%, respectively, with corresponding values of 5 - 58% and 20%, for 1.5 N/kg. These lesser power values lend support to this alternative explanation for the lack of differences previously reported.

Because of the importance of the knee joint as a shock absorbing mechanism it is important to evaluate its supporting or compromising nature on the GRIF values. As previously indicated the mean main effect difference for shoe hardness of 0.5 degrees (see Table 1) was significant but the planned comparisons within-shoe conditions indicated that this was primarily due to the significant hard shoe

condition with the harder shoe producing a 1.2 degree greater mean MKF value. Evaluation of the single subject results (see Table 2) identified nine significant MKF differences distributed among the three shoe conditions (soft = 3, medium = 2, hard = 4) with seven values being greater for the harder shoe within shoe conditions. Four of the significantly greater values were associated with subjects who exhibited significant GRIF differences (harder > softer) while the five remaining values were associated with subjects not exhibiting significant GRIF values. The correlational analysis between the MKF and GRIF values provided additional insight into the relationship between the two parameters. This analysis produced r values of -0.59, -0.62 and -0.57 for the total, SIG GRIF, and NS GRIF groups of subjects, respectively. The r values and mean explained variance of 35.2% along with the group MKF analysis results support the GRIF analysis that some accommodation took place on average but the extent varied among subjects.

An acknowledged limitation of this analysis was the use of a single parameter (MKF) to represent performance adaptations. However, other researchers (Greene and McMahon, 1979; McMahon and Greene, 1979; McMahon et al, 1987; Dufek and Bates, 1990) have shown this parameter to be a good indicator of performance adjustments and knee stiffness. We are not suggesting that this is the only important parameter for controlling the response but it was able to explain 35.2% of the variance between GRIF and performance providing additional insight into accommodation strategies.

The differential response patterns observed seem perfectly reasonable since it is unlikely that individuals will come to an experimental setting with the same experiences and have the same perceptions of the environment (different shoes) which are necessary to produce the same performance adjustments. Given the vast number of possible influencing factors it is more likely than not that response strategies will occur along a continuum from purely Newtonian where the differences are completely ignored (GRIF values increase predictably) to purely neuromuscular where the system totally accommodates to the differences between conditions resulting in equal GRIF values. A group by condition experiment simply dichotomizes and supports one of the extreme positions on the continuum depending upon the predominance of individual performances along the continuum and the researchers ability to detect real differences of a certain

magnitude, i.e. statistical power relative to effect size. Evaluation of an individual subject dichotomizes performance about a point on the continuum in a similar manner.

Previous researchers (Clarke et al, 1983; Kaelin et al, 1985; Snel et al, 1985; Nigg et al, 1987; Hennig et al, 1993) have also reported a non-significant relationship between GRIF or peak tibial acceleration values and IT results. The present study also produced non-significant results for all subjects ($r = 0.06$), however, evaluation of the SIG group data resulted in correlations of 0.01 and 0.59 with and without the outlier subject (S17), respectively (see Figure 2a). The grouping of subjects using different response patterns/strategies can have a similar affect on correlational results as with group evaluations since the assumption of subject homogeneity is violated. A pure Newtonian response strategy in the absence of variability would result in an r value of 1.0 with 100% explained variance. Based upon the methodology and results of this study it was not possible to identify the contributions from variability and/or a partial adaptation response to the observed unexplained variance but it is reasonable to conclude that at least a portion of the unexplained variance was due to an adaptation strategy. Use of an adaptation strategy by subjects in previous studies could be the reason for the reported non-significant relationships between GRIF and IT values (Clarke et al, 1983; Kaelin et al, 1985; Snel et al, 1985; Nigg et al, 1987; Hennig et al, 1993) or the results could have been due to the grouping of unlike subjects and/or performance variability along with the resulting lack of statistical power.

Since impact forces have been implicated as a cause of running injuries, the magnitudes of the differences between shoe conditions should be evaluated. It has been suggested by DeVita and Bates (1988) that differences greater than 1.0 N/kg body mass could be biomechanically meaningful relative to causing injury. To assess shoe hardness effects relative to this criteria, mean absolute differences were computed for the total group of subjects as well as the subgroups (Table 3). Although the total group produced a mean value (1.10 N/kg) in excess of the 1.0 N/kg criteria this was primarily attributed to the SIG group (1.66 N/kg). These results indicate that the observed shoe differences could be sufficient to cause injury in these runners if they did not eventually accommodate, i.e. modify their performances.

In summary, the ultimate goal of research is to gain a better

TABLE 3

	ALL (n = 18)		SIG		NS	
Variable	ABS	ALG	ABS	ALG	ABS	ALG
GRIF (N/kg)	1.10	1.00	1.66	1.66	0.41	0.14
MKF (degrees)	1.0	0.5	1.5	1.0	0.5	0.0
MKF/GRIF (degrees)	1.0	0.5	0.8	0.5	1.2	0.6

GRIF and GRIF/MKF results for SIG (n = 10) and NS (n = 8) subgroups are based upon the single subject GRIF analyses. MKF results for the SIG (n = 9) and NS (n = 9) subgroups are based upon the single subject MKF analyses

understanding of the underlying mechanisms of performance while the goal of an individual experiment should be to maximize the amount of information made available. The more complex less traditional design used in the present study allowed for the evaluation of the data from several different perspectives which provided additional insight into the interactive nature between performer response patterns and analysis technique. The results support the hypothesis that subjects can and do respond differently to the same perturbation and that these differential responses can compromise group analysis results. Response patterns or strategies appear to lie on a continuum between purely Newtonian or mechanical and purely neuro-muscular or accommodating. The results from the present study suggest that although some adaptation is usually exhibited by most subjects, some of the previously reported non-significant differences between shoe conditions could have been the result of differential adaptation patterns and/or non suffficient statistical power. These findings further suggest the need to modify the way we approach the study of some human performance problems, especially where individual results such as injury and performance enhancement are important.

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