POWER OUTPUT OF AMERICA'S CUP GRINDERS CAN BE IMPROVED WITH A BIOMECHANICAL TECHNIQUE INTERVENTION.

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DECLARATION

The work presented in this thesis is the original work of the author except as acknowledged in the text. I hereby declare that I have not submitted this material either in part or whole for a degree at this or any other institution.

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ABSTRACT

Grinding set-up in America’s Cup sailing provides the power behind tacking and gybing, where the yacht crosses the wind to change direction. Grinding is also used for trimming the sails, which changes the angle on which the yacht is headed. This study provided a descriptive biomechanical overview of grinding on an America's Cup class yacht, and experimentally evaluated the influence of technique instruction on backward grinding performance. Inter-subject differences in body position (technique) throughout the grinding cycle, the ability to alter grinding technique within an eight-day technique intervention period, and the effect of technique on grinding performance as determined by power output were assessed.

The quasi-experimental design, in which each of eleven Team New Zealand America’s Cup grinders served as their own control, assessed four trials of backward grinding at baseline and post-biomechanical technique intervention testing sessions. Each trial was a maximal effort performed against a high load (250 W) and sustained over a period of eight seconds. Sagittal plane video was used to analyse joint kinematics (elbow, shoulder, trunk, hip, knee, ankle angles and joint centre positions) and to calculate the centre of body mass relative to the grinder pedestal. Height, weight, and limb lengths were obtained from each grinder using the ISAK protocol.

Current backward grinding technique employed by the majority of grinders did not optimally use biomechanical principles. Recommendations for improvement were specific to each individual but focused on lowering trunk position and distancing the trunk from the grinding pedestal. Real-time visual feedback was provided to the grinder operators with the main focus being the position of their hip joint (viewed in the sagittal plane), and lowering the shoulder to be vertically level with the apex of the grinding handle cycle. During the intervention the grinders were given added correctional instruction relating to their body position according to perceived technique requirements. Recommendations were based on biomechanical principles regarding body position, and how body position could be altered to optimise the contribution of body weight and force production by the muscles of the upper limb in order to improve the torque applied to the handles.

Altering grinding technique according to biomechanical principles produced 4.7% (p = 0.012) greater power during five seconds of grinding performance. Muscular strength, when measured using a 1RM bench pull (116.4 ± 9.8 to 117.3 ± 10.3), was unaffected by the intervention program, thus not contributing to the increased power output observed during grinding. Moderate changes to body position were observed after the eight-day intervention. Forward lean of the trunk decreased from 25° to 17° (p = 0.028) due to a lower hip$_y$ position (-0.09 m to -0.16 m below hub, p = 0.019). The more vertical trunk alignment resulted in the shoulder$_x$ position being further from the hub (0.33 m to 0.41 m, p = 0.013), producing a greater line of pull due to a more efficient shoulder vector angle (47° to 36°, p = 0.009). Variability (standard deviation and confidence intervals) decreased in all but four kinematic measures (which exhibited no change) indicating improved consistency in grinding technique.

Regression analysis indicated the best predictors for high-load backward grinding performance were COM$_x$ position relative to the grinding pedestal and maximal strength. Changes in COM$_x$ position explained 40% (p = 0.166) of the variation in grinding performance, while maximal strength showed a relationship of 0.23% (p = 0.144) increase in performance per kilogram of bench pull 1RM. A one standard deviation difference in maximal strength altered the effect of COM$_x$ position by 0.26% per centimetre (p = 0.008). Weaker predictive factors were body weight, standing height, and pull angle, while brachial index did not appear to have any substantial influence on backward grinding performance.

For future research greater subject numbers should enable more conclusive findings, especially in terms of the technique mechanisms and their relative levels of influence on performance.

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GLOSSARY

The following sailing and biomechanics terms are used throughout this thesis:

Anthropometry	The measurement of physical dimensions of the human body.
Brachial Index	A percentage measure of the length of the forearm relative to the length of the upper arm segment.
Centre of Mass	A single positional co-ordinate representing the average position of all segments of the body combined.
Gybe	A change in direction where the boat crosses the wind and is sailing downwind/with the wind coming from behind.
Kinematics	The description of movement in terms of both time and position in space.
Power (W)	Product of force and velocity of movement. Used as a measure of grinding performance along with "work".
Range of Movement	In this case measured in centimetres (cm) as it refers to the displacement of the actual joint location in space.
Tacking	A change in direction where the boat crosses the wind and is sailing upwind/against the wind.
Trimming	Altering the "shape " of the sail in order to change the angle and heading of the boat.
Torque (N.m)	Product of force and the perpendicular distance to its line of action, which causes a rotation about a specific axis.
Work (kJ)	Measure of cumulative power production over a period of time.

CHAPTER ONE – INTRODUCTION

The current thesis aims to provide a descriptive overview of grinding on an America's Cup class yacht, and to experimentally evaluate the influence of technique instruction on grinding performance. A grinding set-up (see Figure 1) provides the power behind tacking, gybing and tacking/gybing duels, where two yachts turn back and forth in an attempt to out manoeuvre and/or tire their opposition (Armitage, 1997). Grinding also is used in trimming the sails, which alters the sail "shape", resulting in changes in direction without crossing the wind.

Figure 1: External structure of an America’s Cup class yachts’ grinding set-up.

Note: Image courtesy of Harken, Inc.

The grinding set-up on an America’s Cup yacht consists of two components: the mechanical grinding pedestal and the sailor who operates the equipment. As both the mechanical and human components of this set-up are commonly referred to as the “grinder”, this review will refer to the human component as the “grinder operator”. The exterior of the grinder (see Figure 1) consists of the grinding pedestal, which projects 87 cm up from the floor, and two large hand cranks which are orientated at 180 degrees from each other, one on either side of the pedestal. Handles are situated at the end of the crank arms making the overall set-up similar to an upper limb bicycle. Unlike a bicycle however, work can be completed with the grinder cranks turning in either direction (depending on gearing). Grinding drives the winches attached to the sail lines, which are responsible for the movement of the sails - the propulsive force behind the yacht. A large amount of resistance is placed on the grinder system due to the large amount of pressure held in the sails. As a result, it can often be very difficult to turn the cranks even with the different gears available through the grinder. Given that large amounts of force need to be produced in a short period of time (a single tack/gybe), and repetitively over the course of a race, the effectiveness and efficiency of the grinding set-up can have a significant affect on the overall performance of a boat.

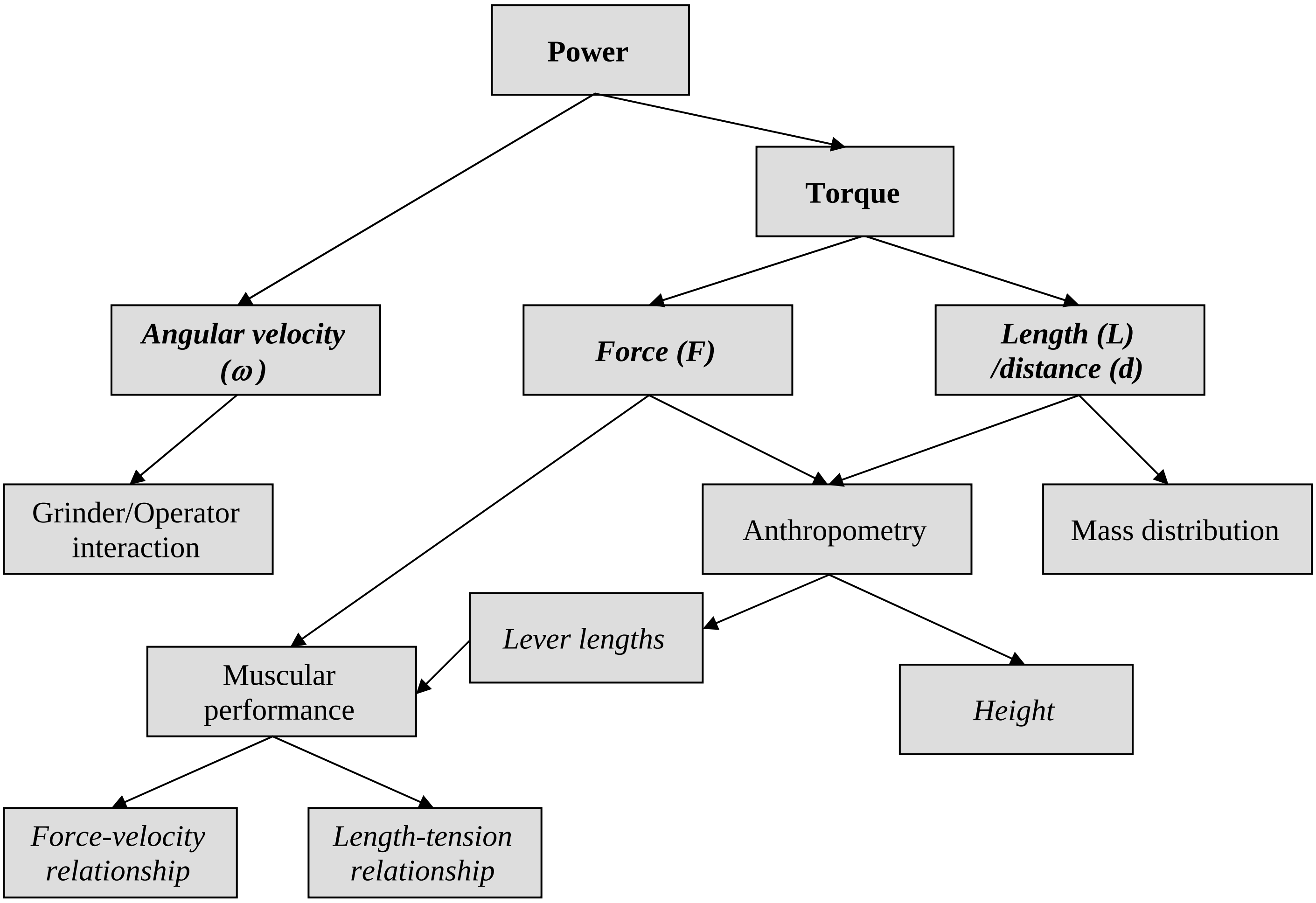

Figure 2: Deterministic model showing the components involved in torque or power production and grinding performance.

Figure 2 illustrates the main determinants of grinding performance. The effectiveness of the mechanical grinding set-up is determined by the amount of torque produced at the grinder hub, where the drive created at the handles is then transferred to produce movement of the sail lines. Torque is the ability of an applied force to cause a rotation around an axis (Hamill and Knutzen, 1995), and is defined by the force applied and its perpendicular distance from the axis of rotation ($T = F \times d \perp$). The performance of the human component or grinder operator, however, is best defined by the amount of power that can be produced using a given set-up. Hull and Gonzalez (1988) defined power for a cyclic movement, such as the one previously described, as the product of applied force, length of the crank arm and angular velocity of the movement ($P = F \times L \times \omega$). Applied force in both of these formulae is mainly dependent on the human component of the set-up and would therefore be affected by factors such as body mass, neuromuscular control (strength/coordination), height, arm length, leg length and brachial index (comparative forearm and upper arm segment lengths). However, force production by the operator will also be affected by mechanical components like the height of the grinding pedestal and length of the crank arms in relation to the dimensions of the grinder operator. The distance from the point of force application to the axis of rotation (d) and the length of the crank arm (L) are essentially the same variable. This is due to the distance from the axis of rotation (grinder hub) to the point of force application (handles) being determined in the grinder set-up by the length of the mechanical crank arm. Angular velocity is the speed at which the grinder hub rotates, and as such is determined by the interaction between the mechanical grinder and the grinder operator.

Of the mechanical variables in the grinder set-up, the one with the most direct influence on torque and power production is the length of the crank arm. Based on the formulae $T = F \times d \perp$ and $P = F \times L \times \omega$, increasing the length of the crank arm should enable increased output without having to increase the applied force (effort) from the grinder operator. Alternatively, decreasing the length of the crank arm will decrease the inertia of the system, enabling a greater rate of force production and higher angular velocity. Manipulation of crank arm length was therefore considered as a possible area of research. While it appears that performance could potentially be enhanced through alterations to crank length according to individual grinder operator characteristics (in particular anthropometric measures), the application of this information would be fairly limited in a practical setting. Grinder operators operate at the same grinder pedestal station for most of the race, however there is movement between these stations during the race and there is often two operators grinding at the same pedestal. As the different grinder operators using the same station may not share the same physical characteristics, individualisation of crank arm lengths would be impractical. An adjustable crank design was ruled out given the stress placed on the system and the likelihood of breaking moveable parts on the crank system. Consequently, in consultation with members of the Team New Zealand syndicate, it was concluded that the greatest improvement in grinding performance could be gained through manipulation of the human component (grinding technique) rather than mechanical manipulation of the grinder. This analysis was considered to be especially significant, as there are currently no guidelines for grinding technique, with each grinder operator simply doing what they (individually) feel most comfortable with. Specifically, the desire is to identify aspects of backward grinding technique that affect the ability of the grinder operator to apply force to the grinder handles under high load conditions. Backwards grinding was chosen due to the greater variation in technique displayed by the grinder operators during pilot testing when grinding backwards compared to grinding forwards. This greater variation suggests that the backward grinding movement is generally less refined and may therefore derive more benefit from a technique intervention. The high load condition was chosen as high load performance has the greatest effect on how the boat performs, and high load conditions also produce greater variation in technique than low load conditions.

Aims

This research aimed to:

1. Investigate the inter-subject differences in body position (technique) throughout the grinding cycle.
2. Investigate the ability to alter grinding technique within an eight-day intervention period.
3. Determine the affect of altering technique on grinding performance as determined by power output.

Hypotheses

It was hypothesised that:

1. There would be large differences in pre-intervention body position between subjects during backward grinding.
2. There would be a significant change in kinematics of backward grinding with a technique intervention based on body position.
3. Altering grinding technique according to biomechanical principles would produce significant changes in the amount of power produced against a given load.
4. There would be no significant change in strength, measured with 1RM, over the eight-day intervention programme.

Limitations

1. Participants were required to perform all testing using an on-land instrumented grinding ergometer. There is no information on the validity of an on-land ergometer to replicate on-water grinding. Within this study all changes were relative to previous performances on the grinding ergometer as all testing conditions were performed on the same ergometer. Care was taken when reporting these results and making assumptions with respect to on-water grinding, given the possible changes in body position required with increases in boat lean.
2. During data collection there was unavoidable occurrence of noise. Every step possible was taken to minimise noise.
3. The motivation of the subjects may not have been optimal. Verbal motivation was given to the subjects throughout the tests and a competition environment between the grinder operators was encouraged.

Delimitations

1. The subjects were male aged between 20 and 45 years. All subjects had at least two years of high level grinding experience and were training as members of the Team New Zealand America's Cup syndicate.
2. Technique recommendations were limited to aspects of technique expected to improve backward grinding under high load conditions.

CHAPTER TWO - BACKGROUND

Introduction

At the time this project was conducted there was no research publicly available on the biomechanics of grinding. It is possible that private research has previously been produced, but due to the commercially sensitive and therefore highly secretive nature of the America's Cup competition the research was not publicly released. Literature from related activities (in particular cycling) was reviewed for possible insights into grinding mechanics and performance, however, while the repetitive movements of grinding and cycling are similar, the difference in the movement mechanics of the upper body (grinding) and the lower body (cycling) mean that any crossover information between the two activities could never be very specific.

Due to the lack of relevant pre-existing literature on grinding on an America's Cup class yacht, the majority of the background information presented here was obtained through the pilot testing for this project[1]. Alternatively, in circumstances where pilot testing was not possible (such as on-water performance) it was necessary to obtain anecdotal information from the relevant members of the Team New Zealand syndicate. Although there are obvious limitations in relying on the scientifically unsupported observations of individuals, the individuals in question are all highly skilled in their areas of expertise. It was also in the best interest of the Team New Zealand syndicate to provide the best possible information for this project, and given the circumstances there was no viable alternative.

In order to understand how technique may be altered to improve the performance of backwards grinding under high load conditions it was first necessary to identify which factors influence performance. The following sections review the results of pilot testing in terms of interactions between strength, various anthropometric variables, and grinding performance. The theoretical basis for changing grinding technique and the realities of practical implementation are also addressed, based on a combination of related literature and observations from pilot testing. Due to the original nature of this research it was necessary to justify the experimental protocol used and also the reliability and validity of some of the

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[1] Pilot testing for this study was conducted between September 2001 and February 2002. Results are contained in Appendix 1.

equipment used. In particular the ergometer used for testing grinding performance needed to undergo reliability testing, as it was custom-built for this investigation. Justification and details on the pilot testing of the protocol and equipment are presented in the final two sections of this chapter.

Optimisation of grinding technique

As there was no background on grinding and what defines good technique it was necessary to design the intervention technique on general biomechanical principles. The main determinant of grinding performance is the amount of torque that can be applied by the operator to the mechanical grinder. As it was explained previously[2], torque is the ability of an applied force to produce a rotation. Torque is defined in grinding by the amount of force applied to the grinder hub via the handles and the distance from where the force is generated to the point of its application to the system. Power output is the human performance measure used in this study. The inclusion of angular velocity provides a better representation of how the human and mechanical components interact to produce movement of the handles - the main aim of grinding.

Figure 3 shows a schematic representation of the body position used for backward grinding by the majority of the Team New Zealand grinder operators prior to this study (A), and the "target" position that was envisaged after the technique intervention (B). One of the main intentions of the proposed technique was to increase the horizontal distance between the grinder operator’s trunk and the grinding pedestal, and to lean the body away from the pedestal during the pull phase. These two position changes should result in the arm being fully extended throughout a large portion of the pull phase, with the forces being generated by movement of the body and the large muscles in the trunk. In addition it was desirable for the grinder operator to decrease the vertical position of their trunk, with the visual aim of having the shoulder joint level with the handle at the top of its arc. The intention of altering body position in the ways outlined was to increase torque production. This should occur through an increase in the forces being applied to the handles and also an extension of the distance from the point of force generation to the axis of rotation.

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[2] See Chapter One - Introduction

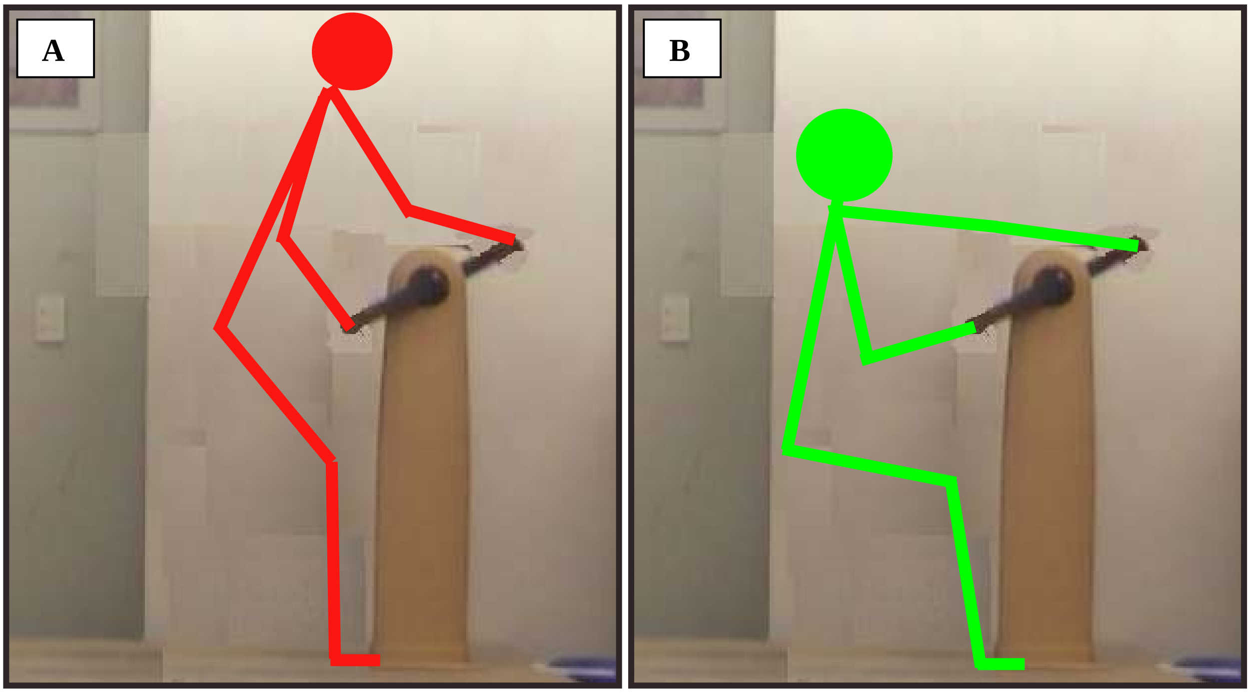

Figure 3: Dominant pre-intervention body position (A) compared to the "target" post-intervention body position (B) for high load backward grinding.

Force production

Force applied to an object – in this case the crank arm handle - can differ in accordance with a number of variables including strength, anthropometry (body dimensions), and technique. Gains in strength and changes in anthropometry involve the physical alteration of the body and therefore occur very slowly. By contrast, technique involves only a change in how a body's present characteristics are applied to an activity and can therefore produce changes in power output within a fairly short period of time. There are two main ways in which the force production should be improved through the implementation of the body position shown in Figure 3b, and both are related to the main line of pull for backward grinding.

Subjective observations from members of the Team New Zealand syndicate and also from video footage suggest that for backward grinding, and especially under high loads, there is a main pull phase. This is executed through the higher of the operator's two hands as it is pulling over the top of the hub toward the operator's body. It is during this pull phase that the majority of the work throughout a cycle is done, and while there is a contribution by the lower hand as it pushes away from the body, this appears to be minimal. The line through which this main pull phase occurs is determined by the position of the shoulder, as the shoulder determines the direction in which the hand can pull the handle. Differences between the direction of the main line of pull for the pre-intervention and proposed techniques are displayed in Figure 4.

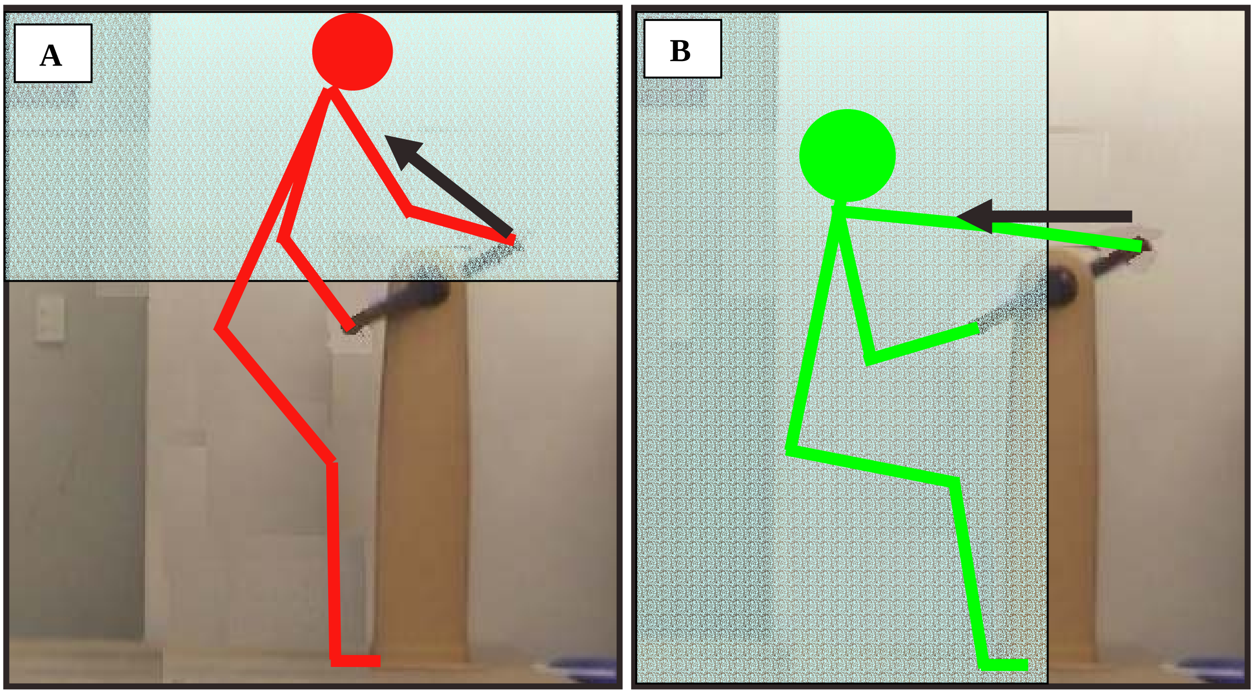

Figure 4: Differences in the line of pull direction between the dominant pre-intervention body position (A) and the proposed body position (B). Shaded areas represent the potential body weight contribution to the pull phase.

The first main advantage of the proposed technique is that the line of pull is much more horizontal than in the pre-intervention technique. As the line of pull is determined by shoulder position, line of pull is best described using the vector angle from the grinder hub (mid-point of the handles) and the position of the shoulder joint. A more horizontal line of pull means that with the proposed technique there will be a reduction in the gravitational force opposing the major work period in the cycle. This is in comparison to the dominant pre-intervention technique which has the main line of pull travelling in a much more upwards direction, which will result in a reduction in the net force applied to the handles due to the detrimental effects of gravity on the movement.

The second advantage of the proposed technique is in the potential contribution of body weight to the main pull phase. The amount of the total body weight that is able to be contributed to the pulling movement in backward grinding is determined by what parts of the body are on the same side of the hub as the direction of pull. Shaded areas in Figure 4 represent how the proposed technique allows almost the entire body weight to contribute to the main pull phase, while the dominant pre-intervention technique effectively precludes the involvement of most of the lower body from the movement. De Leva (1996) estimated each lower limb to make up 20% of total body mass in males. The average mass of the 11 grinder operators in this study was 104 kg, which equates to an average contribution of the lower body to the pull phase of just over 40 kg. This does not include the lower part of the trunk, which may also have restricted utilisation with the more upright body position. Therefore, in the more upright position the contribution of the individuals’ body weight to the pull phase will only be slightly over 60% of its total, meaning that a large proportion of the total body weight available is left unused.

Distance of force application

Extending the distance from the axis of rotation (the grinder hub) to the point of force production can also produce an increase in the torque applied at the grinder hub. In the case of heavy load grinding the majority of the applied force is generated either through the use of body weight, or by the large muscles of the trunk and around the shoulder. The body weight component is best represented by the centre of mass (COM), which is generally located around the middle to lower trunk, although the exact location will depend on individual physical characteristics and posture. As the major muscles contributing to the production of force are also located in the trunk, COM would appear to provide an appropriate representation of the main "location" of force production. The requirement for improving applied torque is therefore increasing the distance between the grinder hub and the individual's COM.

It would be possible to increase the grinder hub to COM distance through manipulation of mechanical crank arm of the grinder but as has been previously discussed[3], this approach is impractical. An alternative method for increasing the length of the effective moment arm - and therefore enhancing the effectiveness of any applied force - is by altering the human component. While altering actual limb length would obviously be a drastic exercise, increasing functional limb length can be achieved by changing the body position assumed by the grinder operator. Changing body position from the dominant pre-intervention technique to the proposed technique would result in the desired extension of distance between the

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[3] See Chapter One - Introduction

body's COM and the grinder hub, which should in turn increase the applied torque and therefore the power output from the grinder set-up as a whole.

Interaction between muscular strength and grinding performance

Due to the large range of grinding loads that occur during race conditions there are a number of muscular performance variables that could be seen to influence grinding performance. At the bottom end of the scale there may be almost no load on the grinder cranks, during which a major determinant of maximal performance will be the rate at which force can be applied to the handles. A higher rate of force application will increase the revolutions per minute (rpm) performed under low load conditions, therefore enabling the required work to be performed in a shorter period of time. At the top end (high load) grinding conditions, however, the resistance in the system requires that the main muscular determinant of performance becomes absolute strength. This is due to the gross force applied to the handles becoming considerably more important than the rate at which the force can be applied, because the greatest rate of force application will be of no benefit if the resultant force is insufficient to move the handles. As maximal effort bursts in on-water competition tend to last less than 15 seconds at low load (shorter when at high loads) short-term muscular endurance is not a significant factor, although the ability to be able to produce over 100[4] or so maximal effort bursts of grinding in a race of over two hours in length is essential for winning performance. This assessment has been supported by recent research from Bernadi, Fontana, Rodio, Madaffari, Brugnoli, and Marchetti (2003) with the Mascalzone Latino syndicate who competed in the 2002-2003 Louis Vuitton Cup competition (qualifying for the America's Cup proper). They examined the energy expenditure of various positions on board an America's Cup class yacht and concluded that both anaerobic and aerobic fitness were important for the performance of a grinder operator. While the ability to anaerobically produce large amounts of work in a short period of time makes a large difference to the performance of the yacht, a short recovery time and the ability to repeat these bursts is also essential.

High load grinding is where the largest performance variations occur between grinder operators[5] and is also considered to be what makes the greatest difference to the performance

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[4] This number is extremely variable depending on weather and tactical conditions in a race.

[5] A further discussion on the variation of grinding performance under various loads can be found in the justification of the experimental protocol.

of the boat on the water. As this study examined grinding under high loads, maximal strength can be considered the muscular performance variable of greatest significance to this study and also to have the most influence on grinding performance as a whole.

Strength measures

Results of strength testing sessions were available for this project from the physical conditioner for the Team New Zealand syndicate. Strength testing using a standardised protocol was a regular part of the fitness programme for all of the active sailing crew in the syndicate. The relevant strength test in this case was the bench pull, a barbell exercise that measures the strength of the shoulder extensor and elbow flexor muscles when used in a pulling movement, which corresponds well with backward grinding.

In the bench pull exercise the testing participant lies prone on a full-length flat bench with one arm on either of the bench holding onto the barbell with a pronated grip. A repetition starts with the arms fully extended below the bench, from which point the barbell is pulled upwards towards the chest, to be approximately in line with the nipples. The testing protocol used by Team New Zealand is common in New Zealand sports and involved continuous repetitions of a certain weight to the point of muscular failure. Load placed on the bar was chosen with the aim of failure occurring between 3-8 repetitions. For a repetition to count it had to be smooth and controlled, be completed throughout the full range of motion, and the chin had to remain in contact with the bench (ensuring the back did not arch and the chest stayed on the bench). Full range of motion was defined as going from arms straight at the elbows to the barbell hitting the underneath of the bench, which in this case was six centimetres thick. Warm-up before testing was unrestricted and sailors were allowed to perform multiple tests if they wished. Even when multiple tests were completed, however, the best result almost invariably occurred in the first attempt[6].

As strength-testing results were already being conducted in a reliable and controlled manner it was considered more appropriate to use the data from these testing sessions rather than unnecessarily repeat measures. The weight lifted and repetitions completed for an individual were then converted into a single repetition maximum (1RM) score using the equation: 1RM

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[6] This observation is based on a statement by the physical conditioner for Team New Zealand.

= 100 × rep weight / (52.2 + 41.9 × EXP [-0.055 × reps]) from Mayhew, Barnett, Schutter, and Bemben (1995)[7].

Correlational outcomes between pilot-testing results of strength testing and grinding performance under high-load conditions are displayed in Table 1. Results showed a significant (P-value <0.01) relationship between the strength and high-load grinding performance for both forward and backward grinding. Analysis shows, however, that those who are strong are not necessarily the best at grinding. The R^2 values indicate over half of the variation in grinding performance was explained by variation in strength (53% for backward grinding, 66% for forward grinding).

These results suggest that while maximal strength is a good predictor of grinding performance under high load conditions there must be other factors involved. The lower R^2 value indicates that these additional factors have a greater influence on backward grinding than forward grinding. Two factors considered to have a potentially significant influence on grinding performance were an individual's technique and anthropometry. The relationship between anthropometry, technique, and grinding performance is examined in the following sections.

Table 1: Correlational analysis of the relationship between high-load grinding performance and maximal strength for 11 male grinder operators.

Variable 1	Variable 2	Correlation	P-value	R^2 value
Backward grinding	1RM Bench Pull	0.726	0.000	0.527
Forward grinding	1RM Bench Press	0.812	0.000	0.659

Interaction between anthropometry and grinding performance

As was detailed in the previous section, the majority of variation in grinding performance under high loads can be explained by variations in strength, although this still left around 35-50% of the variation in grinding performance unexplained. One of the additional factors

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[7] See Appendix 2 for conversion equation details.

considered to have an influence on grinding performance was an individual's anthropometry or physical dimensions.

Anthropometric measures

Several anthropometric measures (standing height, body mass, total leg length, lower leg length, sitting height, total arm length, and brachial index) were considered to have a possible effect on grinding performance. Whilst some of these anthropometric variables were thought to directly affect grinding performance, most were expected to produce an effect on performance as a result of their influence on technique. Due to the lack of literature on grinding none of these potential relationships have been previously documented, however the theoretical basis for these expectations will be explained here.

Brachial index is a measurement of forearm length relative to upper arm length (BI = radius length/humerus length*100). BI is reported to influence leverage properties of the upper limb (Norton and Olds, 1996), and therefore force applied by the hands. Given that the backward grinding condition to be examined in this study is predominantly a "pulling" activity, a higher brachial index (representing a relatively shorter humerus) would be considered beneficial. A relatively shorter upper arm should allow the hand to travel in a more linear path, reducing the "wasted" lateral forces from a curvilinear path of force application in an activity where only straight-line forces are beneficial. This belief is given some support by the research by Hahn (1990) on rowing - another upper body "pull" activity. Highly ranked rowers had significantly longer forearms than other rowers, while having no significant difference in upper arm (humerus) length, which would result in a higher brachial index for the highly ranked rowers.

Along with brachial index, body mass was one of the variables expected to have a direct effect on heavy load grinding performance. It was expected that there would be a positive relationship between body mass and grinding performance because additional mass can be used to apply more force to the handles. This can be done either through leaning in towards the handles to aid the predominantly "push" focused forward grinding, or by leaning away from the handles to benefit the "pull" orientated backward grinding. While the effectiveness of any additional weight will vary according to technique, there should still be an inherent benefit for heavier grinder operators. In addition, there is no particular disadvantage for added body mass in the grinding movement as the required forces are applied through the hands, which are not supporting the body weight. In the America's Cup competition, however, there is a weight restriction for the sailing crew so gains or changes in body mass of an individual must be balanced out through the entire team.

The effect of the other anthropometric variables of interest on grinding performance is not quite so distinct. Standing height, total leg length, lower leg length, sitting height, and total arm length are thought to potentially affect grinding performance but their influence is rather indirect as it is dependent not only on the individual variable, but on interaction with other anthropometric variables. Total leg length (greater trochanter to floor), and total arm length (acromion process to radial styloid process) will affect the distance an individual can stand from the grinding pedestal. There is likely to be an optimal lower limb length for maximal grinding performance – sufficient to place the feet past the grinding pedestal. Increasing the distance of the COM from the point of force application should result in an increase in torque and improve performance, meaning that longer limbs should be beneficial to grinding performance. Lower leg length and sitting height (trunk length) will have an effect on vertical position of the shoulder relative to the apex of the grinder handle, as particularly long lower leg and trunk lengths could make it difficult to attain the desired alignment between these two points.

While all these segment length variables could have individual effects on grinding performance, it was thought that conducting analyses on all of them would be rather cumbersome. Therefore, based on the generally high correlations between the relevant segment lengths and standing height exhibited by the group of grinder operators used in this study (see Table 2), standing height was chosen as the main anthropometric length variable for analysis. The good correlations found between standing height and segment lengths were consistent with findings by Trivitayaratana and Trivitayaratana (2001) and Cheng, Leung, and Lau (1996). Trivitayaratana and Trivitayaratana examined 428 subjects and found good correlations with height for upper arm length (r=0.789), lower arm length (r=0.826), and knee to floor height (r=0.810). In addition the combination of upper arm length, lower arm length, and knee to floor height measurements provided enough predictive ability to estimate height. Cheng et al. (1996) conducted statistical analysis of segmental bone length data from 3,647 children aged 3-18 years, which showed linear correlations ranging from 0.965 to 0.983 for standing height with arm span, sitting height, and lower segment length. Based on the findings presented here, the use of standing height to represent individual segment lengths appeared to be valid.

Table 2: The relationship between standing height and segment lengths for 11 grinder operators.

	Sitting height	**Total arm length**	**Total leg length**	**Lower leg length**
Correlation with standing height**	0.789	0.917	0.933	0.918
Sig. (2-tailed)	0.004*	0.000*	0.000*	0.000*

*All measures were significant at the $p < 0.05$ level.

**Pearson two-tail correlation

Justification of experimental protocol

Pilot grinding testing conducted between September 2001 and February 2002 was used to provide the basis for the design of the research project and therefore incorporated a variety of measures derived from the expected theoretical biomechanical effects.

Load conditions

The decision to examine grinding under high load conditions was made based mainly on consultation with the Team New Zealand syndicate, with grinding performance under high loads considered to make a greater difference to the performance of the boat. An additional factor was that variations in technique and performance are accentuated when grinding under higher loads, giving the possibility of greater improvements with the implementation of a technique intervention.

Grinding direction

Grinding can be performed in two directions:

- Forward - where the handles rotate away from the grinder operator at the top of their arc, making grinding forward a predominantly "push" based activity.
- Backward - where the handles rotate towards the grinder operator at the top of their arc, making grinding backward a predominantly "pull" based activity.

Although the exact ratios will vary between individual races, it is considered that in general there is no significant difference in the amount of backward to forward grinding performed during competition. Given the lack of a preferential grinding direction according to competition relevance the decision to look specifically at backward grinding was mainly based on the likelihood of producing a significant performance outcome. As was outlined earlier in this chapter, strength is considered to be a major determinant of grinding performance, especially under high load conditions[8]. However, the relationship is weaker for backward grinding, with only 53% of the variation in grinding performance explained by variation in strength as opposed to 66% for forward grinding. This indicates that a greater amount of the variation in grinding performance is caused by other factors, and since an individuals anthropometry remains consistent it seems most likely that this additional variation in due to differences in technique. The greater variation in backward grinding performance should allow for larger changes in performance with a technique intervention.

Time period

The experimental protocol used in this study was an eight-second trial with output analysed for five seconds from peak power. The time for the trial was shortened from the initial pilot protocol that consisted of 12-second trials with data analysed for 8 seconds from peak power. Statistical analysis of pilot trials showed a very high correlation between the results for five and eight second analysis for all testing conditions (α=0.891 to 0.998), with all results being highly significant (p<0.01). As the eight-second trials still fulfilled the requirements for competition specificity (duration and intensity) whilst also reducing the likelihood of subject discomfort or injury, it was concluded that a shorter trial was more suitable for this study. The performance work period of five seconds was necessary to have a consistent work period for each subject. The combination of hand-timed trials and differences in starting and stopping reaction times meant that there was a certain amount of variation in the actual amount of time spent grinding. Beginning the performance work period at the occurrence of peak power resulted in the exclusion of the acceleration phase - while the initial inertia of the grinder and its load are being overcome - and therefore "slow starters" were not disadvantaged in any way. Even given differences between individuals within the group, peak power almost invariably occurred between one and two seconds following initiation of the trial, giving a fairly consistent but also individually specific starting point.

Duration of intervention period

One of the significant influencing factors in the duration of the study was the availability of the subjects. Due to the busy schedule of the Team New Zealand crewmembers it was only

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[8] See the section on the interaction between muscular and grinding performance.

possible for the study to be conducted over the space of 1-2 weeks. Although this was a major restriction there were also other factors that influenced the length of the intervention period. The strong relationship between strength and grinding performance made strength a consideration in the selection of an intervention period. To reliably attribute any changes in performance over the intervention period to changes in technique it is necessary to minimise the possible effects of confounding factors - in this case strength. It was hoped that an eight-day protocol would allow enough time for the grinder operators involved to practice and adapt to the new technique, while ensuring that any change in strength should be fairly insignificant. An additional consideration was that the grinder operators would be in as similar physical condition as possible for the two testing sessions. In most circumstances this would require something like a seven-day protocol so that testing would fall on the same day of the week, however, the rotation of the Team New Zealand training programme was such that by using the eight-day protocol the grinder operators would be completing the same work out on the morning of each testing day. Therefore they should have been in much the same state of muscular fatigue for both the pre and post-intervention testing sessions.

Number of trials

Observations from the pilot testing sessions showed a tendency for the power output during one trial in each session to be noticeably lower then the others. In the majority of circumstances the poor trial occurred in the first trial. Based on this occurrence it was decided that four trials should be conducted for each subject, with the first two trials discarded. This allowed the elimination of trials that may have been affected by warm-up or any additional learning effect while still retaining two trials for analysis. It was hoped that this approach would result in a more accurate representation of an individual's performance.

Camera position

In order for video footage to be useful it is necessary that it capture all the relevant parts of the movement with an appropriate level of detail. No studies were available describing appropriate camera positions for best capturing grinding movement; therefore pilot testing provided a useful opportunity to refine camera placements. This study incorporated one 2-dimensional digital video camera, filming at 25Hz in the sagittal plane (side on). As grinding is predominantly an anterior-posterior movement the sagittal camera was responsible for capturing the kinematics to be used in analysis of the movement. It was placed perpendicular to the line of movement in the sagittal plane. The 25Hz sampling frequency of the video camera used was sufficient for the grinding movement performed in this study due to the high loads the trials where conducted. Had the load been of a lower level, however, a faster sampling camera would probably have been required due to the increased movement speed associated with reduced resistance.

Marker placement

Six joint markers were placed on the right hand side of each subject. The use of markers was intended to decrease the variability in the kinematic analysis conducted using the video footage. In placing markers on the right side of the body only it was assumed that movement patterns are essentially symmetrical between both sides. Due to the lack of literature on grinding the correctness of this assumption of bilateral symmetry between the right and left sides of the body has not been documented. Quigley and Richards (1996), however, found identical trends in contralateral lower limb mechanics for cycling. Although grinding deals with the upper limb compared to the lower limb, cycling is the activity with the greatest resemblance to grinding in that they are both cyclic movements constrained in a circular path by attachment to crank arms, either via handles or pedals. Two-dimensional analysis was used to measure changes in specific technique parameters thought to affect force production and application of force to the grinder handles.

Grinding ergometer considerations

The grinding ergometer used for testing was a new piece of equipment constructed specifically for this research. As a result, a number of issues needed to be considered before using this equipment in an experimental setting. These included reliability for repeat tests, validity of the ergometer as a measure of grinding performance, and familiarity of the subjects with the equipment.

Reliability

Test-retest reliability conducted for the grinding ergometer during January 2001 consisted of two testing sessions, during which three grinder operators each performed two forward grinding trials at a low resistance. The forward grinding, low load condition was chosen because in previous testing sessions it had been shown to have the least amount of trial-to-trial variation within a session. As the aim of this testing was to ascertain the reliability of the grinding ergometer it was necessary to use the condition with the greatest inherent stability in order reduce the effect of noise created by typical subject variation.

The two reliability sessions were conducted at the same time of day and were separated by seven days, a short enough time period that results should not be confounded by any training effect (see Table 3), and the time period between pre and post intervention tests. Test-retest reliability was calculated using an intra-class correlation coefficient (ICC), which showed very good stability between the two testing sessions (ICC = 1.000, *p* = 0.018).

Table 3: Means, standard deviations (SD), and coefficients of variation (CV) for grinding ergometer power output for test and retest sessions, along with the between session change (%).

	Test			**Retest**			
Subject	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**	**% Change**
A	51237	227.6	0.44	50384	495.3	0.98	-1.66%
B	48619	918.0	1.89	48742	402.4	0.83	0.25%
C	48044	27.1	0.06	48313	635.2	1.31	0.56%
Group average	**49300**	**390.9**	**0.80**	**49146**	**511.0**	**1.04**	**-0.31%**

Validity

Unfortunately it was not possible to get a quantitative measure of the relationship between performance on the grinding ergometer used in this study and performance in a competition setting. This was due to the set-up of an America's Cup class yacht. While there was instrumentation on board to provide information on the summed output of the grinding pedestals, there could be multiple pedestals contributing to this output at any one time and there are also frequently two crewmembers at each pedestal. Therefore there was no way of accurately measuring how much an individual was contributing to the overall output, and as the ergometer testing was on an individual basis the information could not be usefully compared. The common use of two crew members at a single pedestal during racing brings into question how this might cause ergometer grinding technique to differ from on-water technique. On-water video footage and reports from crew members, however, indicated that the grinding kinematics differed very little as a result of “sharing” a pedesal, as the positional arrangement on the boat is such that if two crew members are working at a pedestal, they very rarely impede each others movement.

In terms of the measurement accuracy of outputs, this was not determined as part of this study. The ergometer itself was constructed by International Dynamometers Ltd using a combination of dynamometer technology used in vehicle testing and grinding pedestal components supplied by Team New Zealand and Harken Inc. The grinding ergometer was constructed by International Dynamometers Ltd with the express purpose of providing a comparative measure of grinding performance for Team New Zealand. Due to the competitive and commercial sensitivity of any information pertaining to the America's Cup, Team New Zealand and International Dynamometers Ltd made a conscious decision that no calibration would take place on the ergometer. Therefore, outputs would provide no information other than as a comparative reference to other tests on the grinding ergometer. In order to provide additional meaning to the output values in this study, a conversion factor was obtained from International Dynamometers Ltd to change the "power" output values into Watts (W). It should be noted that the power (W) values displayed in this study are only estimates. As the dynamometer was designed for testing car engines, when attached to the grinding ergometer the dynamometer was working at much lower speeds (60-120 rpm) than the normal operating range (400+ rpm), although International Dynamometers Ltd reported good linearity of measures throughout a range of speeds. Therefore, due to conflicting factors, the prediction of exact power values became more uncertain than if testing within the more established range. This does not, however, have any effect on the general findings of this study, as performance was exclusively examined in terms of percentage changes, which are not affected by the units involved.

Familiarisation

Over the period September 2001 to February 2002, the members of Team New Zealand who intended to be part of the main research project were involved in a number of testing sessions on the grinding ergometer. Sessions varied in the exact content and protocols used, but each consisted of a variety of conditions with trials being run under a range of loads and for both forward and backward grinding. All participants in this study were involved in a minimum of two pilot testing sessions, with an average of one hour per session.

This pilot testing had the double function of familiarising the subjects with the equipment along with providing performance data for individual grinder operators under a variety of conditions (forward and backward grinding/high and low resistance). The performance data was used privately by the Team New Zealand syndicate in its own development programme, in addition to providing background data for this study.

Summary of limitations of previous research, and proposed research

There is currently no available research relating to the biomechanical parameters and performance of grinding. The grinders are pivotal to the execution of most manoeuvres on an America’s Cup class yacht (Armitage, 1997) so any improvement in performance for the grinders would be of benefit to the overall performance of a team. As the effects of changing grinding position on grinding technique and performance are unknown this study should benefit the Team New Zealand America's Cup syndicate as well as contributing information to an area of research that is currently very sparse.

In summary, the main points relating to performance of the grinding activity are:

- The amount of torque applied to the grinding set-up is the main determinant of power output, the variable used to measure grinding performance.
- Either increasing the applied force or the distance from the point of force generation to its point of application can improve torque.
- Maximal muscular strength has a significant effect on grinding performance (especially under heavy load conditions) and is a major factor in the generation of force.
- An individual's anthropometry or physical characteristics are likely to influence their grinding performance, both through force generation and helping to determine the length of the effective lever arm.
- Due to the diversity of body positions and large amounts of performance variation left unexplained by strength and anthropometry, it would appear that technique has some effect on grinding performance.
- It is recommended that applied torque could be improved by increasing the distance from the grinding pedestal to the operators' COM and lowering the shoulder position to the level of the apex of the handle rotation.

With respect to the methodological considerations for this study:

- The grinding ergometer used for testing has been shown to be reliable and its validity appears to be sound according to the restricted methods of determining validity available to this study.

- Trials were set as backward grinding under high loads for a period of eight seconds with power output analysed for five seconds following peak power. These conditions were determined according to specificity and relevance to competition and the potential benefits' of a technique intervention.

The main variables of interest for statistical analysis were:

- Power output during the five-second grinding trial (kJ). As the performance measure this was the most important indicator of how successful the intervention was.
- Angle of the grinder hub to shoulder vector (°) and the horizontal distance from the COM to the grinder hub (cm). These were envisaged to be two best measures of whether the desired kinematic changes were made, specifically: increasing COM distance from the hub and decreasing pull angle.
- Height (cm), weight (cm), strength (kg), and brachial index (%). These measures represented the main individual characteristics that were thought to have the greatest effect on grinding performance.

CHAPTER THREE – METHODS

Introduction

The purpose of this study was to investigate the effect of altering body position in grinding technique on the performance of backward grinding under high load conditions. All testing was conducted at the base of the Team New Zealand America's Cup syndicate.

Preliminary testing of the proposed equipment and procedures has indicated the videography protocols and grinding ergometer set-up to be both reliable and valid[9]. The methods for this study are considered to be original as there is no available record of any previous research into the biomechanics of America's Cup grinding. The testing protocols were designed to simulate the intensity and work periods for high load backwards grinding on an America's Cup yacht as closely as possible. This study received approval by Auckland University of Technology Ethics Committee on the 27th August 2001 (AUTEC Reference number 01/85).

Video data were analysed using Video Expert II software and custom analysis programmes developed using Labview software.

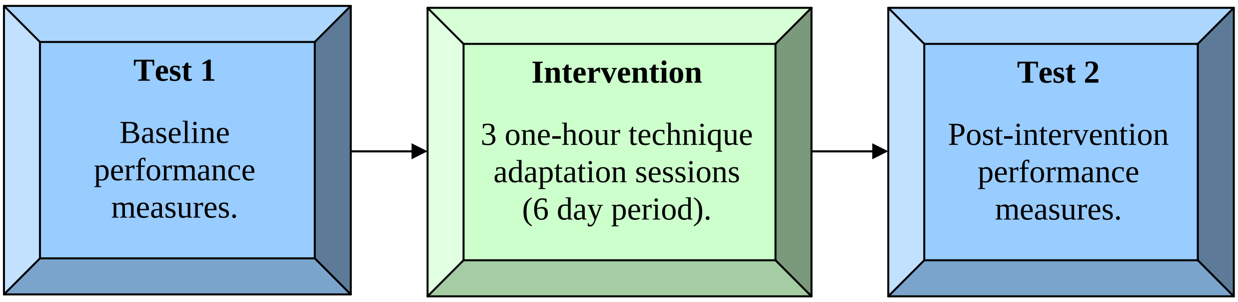

Figure 5: Protocol for the grinding technique intervention.

Experimental design

The study was a quasi-experimental design in which the subjects acted as their own control. Repeated measures were conducted for each session and each subject was familiarised with the experimental equipment set-up prior to the commencement of testing. Testing consisted

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[9] See: Justification of experimental protocol (Chapter Two - Background).

of two sessions: a) an initial testing session for baseline measures, and b) a retest session following the technique intervention. The basic protocol is outlined in Figure 5.

In both the baseline testing and post-intervention testing sessions each subject was required to perform four trials of backward grinding under a high load (250 W). Each trial was maximal and sustained over a period of eight seconds. Subjects had a five-minute rest period between each trial.

The independent intervention variable for the experiment was:

- Technique instruction given to grinder operator

The mechanism variable through which change in performance would occur:

- Body position of grinder operator

The dependent variables for the experiment were:

- Power output over five seconds (J)
- Ankle angle (°)
- Knee angle (°)
- Ankle-hip angle (°)
- Ankle-hip distance (°)
- Hip angle (°)
- Trunk position/lean (°)
- Shoulder angle (°)
- Elbow angle (°)
- Hip position/displacement (cm)
- Shoulder position/displacement (cm)
- Center of mass position (cm)

To determine the effects of the verbal instruction on altering technique and subsequently performance, the previously specified dependent variables were measured and compared between the test and re-test sessions (Day 1 and Day 8 of the experiment respectively).

Subjects

A desired sample size (n) for this study was calculated as 25, based on δ =effect size*$\sqrt{n}/2$ (Howell, 1992), where the desired effect size is 0.8 (large) and the desired significance level is 0.05 ($\therefore \delta = 2.8$). The actual sample size was smaller than this however, due to the number of America's Cup calibre grinder operators available from the Team New Zealand syndicate being limited (n = 11, reduced to 10 for some analyses). Due to the restrictive conditions of this project it is accepted the small sample size may limit determining significant results.

Subject recruitment

An agreement was reached with the Team New Zealand America's Cup syndicate regarding the provision of subjects for this research project. In accordance with this agreement, all subjects involved in this research were current members of the Team New Zealand syndicate. Each subject was informed of the requirements of testing, including the strenuous nature of the exercise protocol, which was in common with normal training and competition.

Subject requirements

The subjects were representative of a population of America's Cup calibre grinder operators. Each subject was required to be:

- Male
- Training as a grinder operator for the Team New Zealand America's Cup syndicate
- Healthy with no current limiting injuries or sickness

Procedures

The procedures followed for each subject are now described. These include the measurement of anthropometric variables, and the completion of grinding test and intervention sessions. Subjects were tested as part of a group, and the protocol required five hours over an eight-day period for each subject.

Preparation of the subject

All procedures were explained to each subject, any questions answered and then written consent for participation was gained. The subject consent form and subject information package can be seen in Appendices 3 and 4 respectively. Each subject attended familiarisation and technique adaptation sessions in addition to completing both the test and re-test sessions. A full anthropometric profile of the 11 sailors was measured according to the procedures of the International Society for the Advancement of Kinanthropometry (ISAK) including weight, total height, lower, upper, and total leg length, acromiale-radiale (humerus) and radiale-stylion (radius) length, and sitting height. The measurements of the humerus and radius were used to calculate brachial index (BI = radius length/humerus length*100). All anthropometric measures were taken by an anthropometrist with ISAK level 2 accreditation or higher. Triple measures for skinfolds and double measures for all other variables were collected.

Familiarisation sessions

Prior to the commencement of testing and the intervention each subject attended a minimum of two grinding ergometer based testing sessions conducted as part of the pilot testing for the main study. These sessions enabled the subjects to become familiar with the testing procedures and grinding on an ergometer rather than in an on-water situation. The sailors commented that grinding on the land ergometer felt similar to grinding on the on-water grinder.

Data collection

Data were collected during all trials using a Sony digital video camera sampling at 25 Hz and digital output data, sampled at 40Hz, from the grinding ergometer. Once the subjects were fully prepared and aware of the exercise procedure, commencement of the performance trial began.

Collection period

Following a verbal start signal provided by a timekeeper, the subject commenced grinding maximally for a period of eight seconds. Grinding was stopped when signalled again by the timekeeper. Using the descriptive data output from the grinder, peak power (W) and work over a five-second period (J) following peak power (see Figure 6) were extracted for analysis. Video analysis was conducted for three grinding cycles, starting on the fourth cycle of the trial.

After the one-week of the intervention period subjects were re-tested for any changes in performance, with comparative video analysis of the test and re-test sessions being used to determine whether recommended changes were implemented. Changes in performance were then quantified through output results from the grinding ergometer.

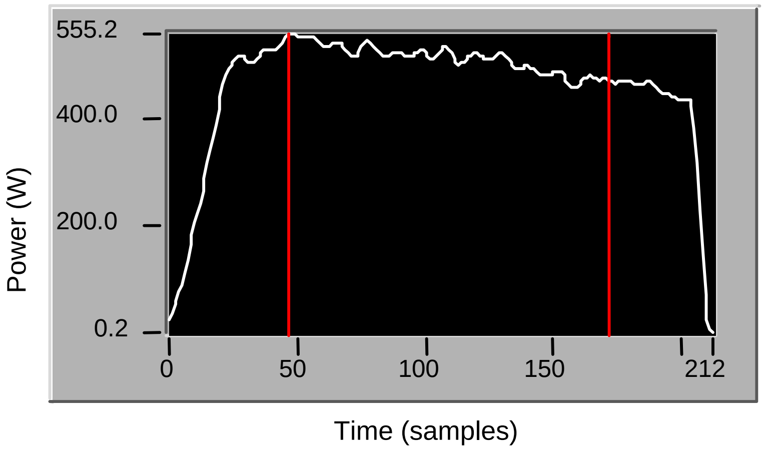

Figure 6: An example power output trace for high load, backwards grinding. The area under the graph between the red lines represents a five-second period used as a performance measure. *Note: 40 samples = 1 second.*

Intervention

Following the initial (baseline) testing, each subject was given individual instructions as to how their grinding technique might be improved. Exact recommendations were specific to the individual subjects but focused on the positioning of the trunk relative to the grinding pedestal.

During the intervention practice sessions the subjects had an easily visible marker located on their hip joint. Instructions were given for each subject to position their hip marker at a certain level on a grid placed behind them from the viewpoint of the sagittal camera. The other main visual marker was for the shoulder to be vertically level with the grinding handle at the apex of its cycle. Over the intervention period subjects were given added correctional instruction relating to the position of their shoulders, hips, and trunk lean according to perceived requirement. All recommendations were based on biomechanical principles regarding body position, and how it could be altered to optimise the contribution of body weight and force production by the muscles of the upper limb in order to improve the torque applied to the handles[10].

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[10] See the "Optimisation of grinding technique" section (Chapter Two - Background) for details

The intervention period lasted for one week, during which the subjects were required to attend three controlled/supervised practice sessions where they were observed and given verbal feedback from the researcher as well as having visual feedback. Visual feedback was in the form of real-time video footage of the subject grinding displayed on a television monitor placed within the subject's normal line of sight. Feedback footage was provided from the sagittal camera. During the practice sessions the grinder operators were asked to implement their recommended technique changes during a cycle of three different conditions (see Table 4). The cycle of conditions was repeated four times during the session.

Table 4: Time period, loading and effort level for practice grinding conditions.

Condition	Time (sec)	Loading	Effort
1	30	Medium	Moderate
2	15	Medium	Maximum
3	8	High	Maximum

Apparatus and data analyses

Grinding kinematics

Testing was conducted on a grinding ergometer with standard dimensions for a main grinding pedestal on an America's Cup class yacht. Gearing for the grinding ergometer was linked through a multiple-speed dynamometer set up to output a number of kinematic measures of grinding performance. The main measure of interest to this study was power output (W), which could be used to quantify the level of performance in terms of the total work over a period of time, and the maximum power generated on the handles. Power output was obtained from the grinding ergometer using a bi-directional oil hydraulic system custom designed to meet the tactile characteristics of the rigging at the grinding station. Speed was based on a 24-slot disc attached directly to motor input shaft. Output was obtained via an analogue to digital converter using 8-bit resolution to a C++ customised data collection system sampling at 40 Hz. Mechanical load was varied using a custom designed cog selector allowing 1:1 and 3:1 ratios driven by toothed belts. Hydraulic load was applied using a dynamic closed loop controller modified to operate at low speed. The computer was a

Pentium 3 with RS232 as the data conduit using Windows 2000 Pro as the operating system. Power was calculated using the formula 2π*n*M/60000 and could be corrected (when turned on) by DIN 70020 (International Dynamometers Ltd, 2002).

Videography

Subjects were recorded in the sagittal (right side) plane throughout all grinding trials. Recording was conducted using a Sony DCR-TRV120E video camera with a frame rate of 25 Hz and a shutter speed of 1000 Hz. The camera was mounted on a tripod and placed as indicated in Figure 7. Hi8 8mm digital videotapes were used to record each trial.

Marker placement

All joint markers were placed on bony landmarks, limiting the effect of muscle activation on marker movement. For sagittal plane grinding analysis six markers were placed on specific anatomical landmarks located by palpation on the right side of the body only. All markers were easily identifiable and were attached securely to each subject with adhesive tape. Marker landmarks used for this experiment were:

- Lateral malleolus (ankle)
- Lateral condyle of the tibia (knee)
- Greater trochanter (hip)
- Lateral surface of the acromion process (shoulder)
- Lateral aspect of the radial head (elbow)
- Styloid process of ulna (wrist)

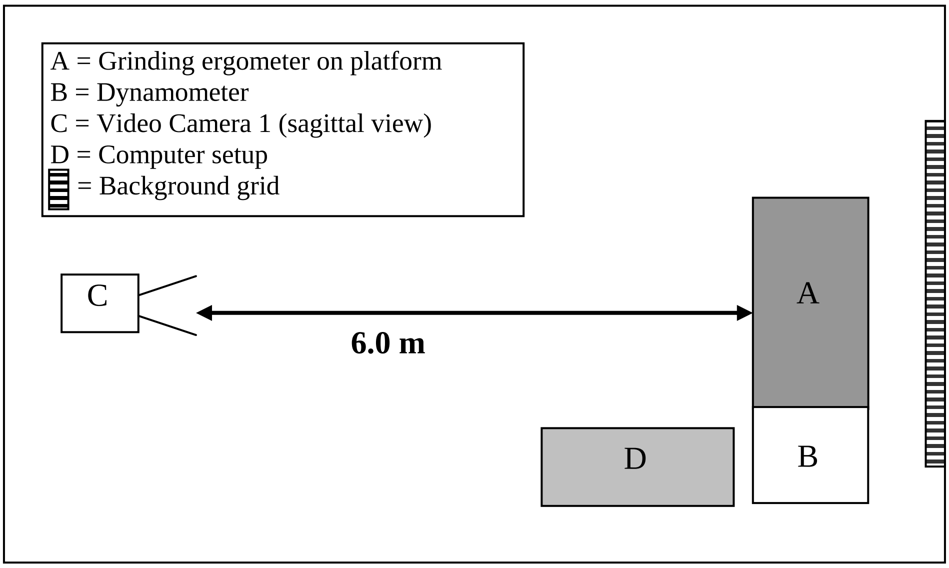

Figure 7: Camera set-up for testing sessions.

Camera set-up

The camera was secured on a tripod and positioned directly perpendicular to the plane of motion, in the sagittal plane. Placement of the camera was such that it ensured the image of the athlete was large enough to identify anatomical landmarks and that both angular and linear distortions were negated. This should allow accurate calculation of the kinematic variables detailed in Table 5.

Table 5: Definition of grinding kinematic parameters.

Variable	Description
Ankle angle	Anterior angle between the tibia and the foot.
Knee angle	Flexion angle of the knee between the tibia and the femur.
Ankle-hip angle	Angle from the ankle to the hip marker with respect to the horizontal.
Ankle-hip distance	Linear distance between the ankle and hip markers.
Hip angle	The amount of flexion occurring at the hip in the grinding position.
Trunk angle	Angle of the trunk with respect to the vertical.
Shoulder angle	The angle of the humerus (upper arm) relative to the trunk.
Elbow angle	The angle of the forearm relative to the upper arm.
Hip position	Location (relative to grinder hub) and movement of the hip marker in both the horizontal (X) and vertical (Y) axes.
Shoulder position	Location (relative to grinder hub) and movement of the shoulder marker in both the horizontal (X) and vertical (Y) axes.
Shoulder vector	Angle and magnitude of the direct distance from the grinder hub to the average shoulder position.
Centre of mass (COM) position	Location of the COM in both the horizontal (X) and vertical (Y) axes.
COM vector	Angle and magnitude of the direct distance from the grinder hub to the average COM position.

Video Expert Vision II system

The Video Expert Vision II™ (VEII) system was used for digitisation of sagittal plane angles. The VEII software allows joint angles to be calculated through two methods: A) automatic generation of angles in degrees or B) generation of x and y coordinates for further manual analysis. The second method was used in this study. Soper (1999) conducted a validation procedure on the VEII software for knee joint angle showing an error of 1.5 ± 0.8° between the two methods. Test-retest reliability of manual digitising of knee joint angle indicated a variation of less than 2° when a randomly selected trial was digitised on two separate days (see Appendix 5 for details).

Calibration or calculation of the scaling factor used to transform the video data to real data was performed for each camera prior to every testing session. Every frame was digitised with joint angles and COM variables were calculated from digitised coordinates using custom-designed Labview™ programmes.

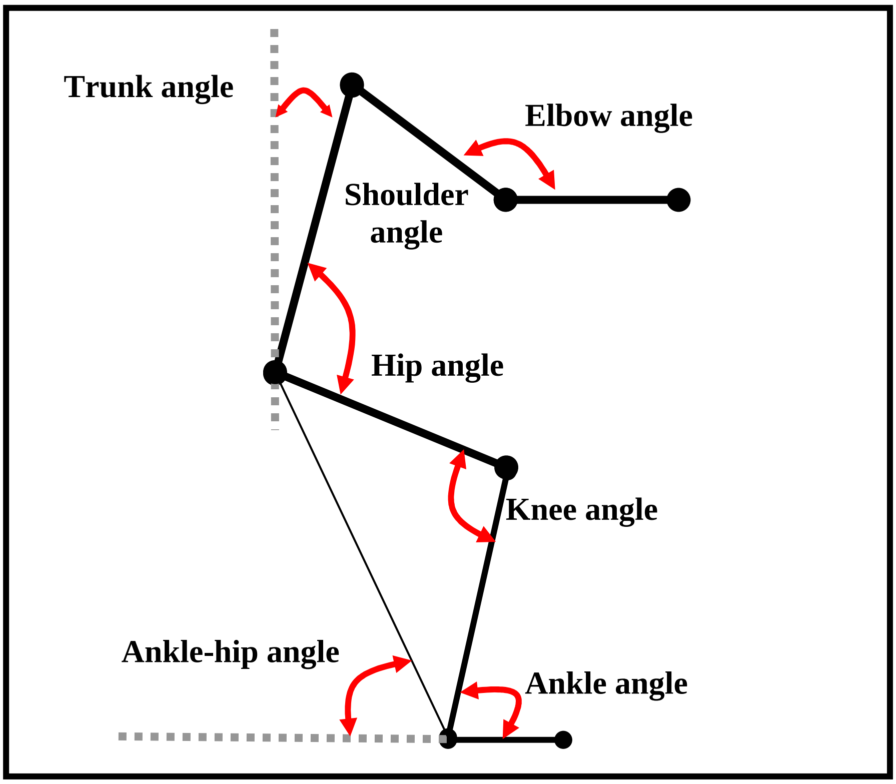

Figure 8: Referencing system for the sagittal plane analysis of a grinder operator.

The referencing system utilised for analysis of sagittal plane angles during grinding is detailed in Figure 8. Joint angles at the ankle, knee, ankle-hip, hip, trunk, shoulder and elbow were measured throughout three grinding cycles, allowing the calculation of mean joint angles and range of movement.

Statistical analyses

Each subject acted as their own control and, with the exception of a pre-intervention inter-subject kinematic comparison, data were compared either within an individual subject or as a group. All data are the result of means extracted from the last two trials of the four trials conducted. Tables illustrating changes in the post-intervention results with respect to the pre-intervention results were developed and a downward arrow (⬇) indicates the post-intervention condition resulted in a smaller variable (such as joint angle) than in the control condition. Appendix 6 contains each subject's individual results, whereas tables within the text usually show average values. The magnitudes of effects were explained using Cohen’s effect sizes.

All data were analysed using the Statistical Analysis System (SAS). Relationships between continuous variables were analysed using the correlation or regression procedure - with the statistic of interest being the coefficient of variance (CV). Relationships between a continuous dependent variable and a discrete or classification variable were analysed using analysis of variance (using the Proc-mixed procedure in SAS). Variables used in this analysis were grinding performance (kJ), horizontal COM distance from the grinder hub (cm), shoulder vector/pull angle (°), height (cm), weight (kg), 1RM bench pull strength (kg), and brachial index (%)[11]. Appendix 7 shows the SAS programme used for statistical analysis.

The Student-paired t-test (two-way) was utilised to test for significance between each dependent variable in the pre and post-intervention test results for: A) kinematic results, B) grinding performance, C) strength testing results, and D) weight. The significance level was set at $p < 0.05$ for all tests.

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[11] Justification for selecting these variables can be found in Chapter Two - Background.

CHAPTER FOUR - RESULTS

The purpose of this research was to investigate the effect of technique recommendations in altering the kinematics of America's Cup level grinders. The technique recommendations were theoretically designed to enable increased grinding performance as measured by grinding power output.

Descriptive data collected for each subject included age (years), weight (kg), height (cm), strength, and additional descriptive anthropometric variables. Power output from the grinding ergometer and kinematic variables of grinding were examined during repeated eight-second maximal bursts of high load backwards grinding. Weight, strength and grinding performance measures were replicated before and after a seven-day technique intervention period. All other measures were taken once, prior to the commencement of the intervention.

Subject characteristics

All individual characteristic variables were measured prior to the commencement of the technique intervention period. Subject weight and the one repetition maximum (1RM) for bench pull were measured on day eight (post-intervention) as well as day one (pre-intervention). There were no significant differences in subject weight or the 1RM bench pull strength for the 11 male grinders who completed the day one (pre-intervention) and day eight (post-intervention) testing sessions. The 1RM strength test displayed the greatest fluctuation between pre-intervention and post-intervention, with the average score increasing less than 1%. Subject characteristics are displayed in Table 6.

Table 6: Individual subject characteristics of 11 male grinder operators.

Subject	**Age** (yr)	**Height** (cm)	**Weight (kg)**		**1RM Bench pull (kg)**		**Upper leg length (cm)**	**Lower leg length (cm)**	**Total leg length (cm)**	**Sitting height (cm)**	**Total arm length (cm)**	**Brachial index (%)**
			Pre	Post	Pre	Post						
1	28	176.3	99.3	99.4	119	117	49.5	45.3	94.8	86.5	60.2	83.5
2	30	185.7	97.4	97.4	105	105	53.6	48.0	101.6	90.7	63.6	76.4
3	29	183	103.3	103.7	114	119	47.8	49.8	97.6	86.0	62.4	80.2
4	26	188.7	98.5	98.9	124	121	49.5	50.9	100.3	87.7	66.2	82.5
5	30	190.3	110.4	110.2	128	128	54.2	50.4	104.5	90.6	65.0	78.7
6	29	182.9	98.2	97.6	99	101	50.2	46.1	96.3	89.4	63.4	79.1
7	29	193.1	102.2	99.5	109	109	52.7	50.1	102.8	90.9	66.8	79.0
8	28	201	118.8	119	131	136	53.0	54.6	107.6	103.8	66.9	77.1
9	32	191.9	105.2	105.2	119	119	53.2	52.2	105.4	90.3	65.7	81.2
10	21	194	120.1	120.3	121	124	53.0	51.4	104.4	92.8	66.2	79.3
11	44	181.2	95.4	96	111	111	47.1	47.3	94.4	90.1	60.5	83.3
Mean	**29.5**	**188.0**	**104.4**	**104.3**	**116.4**	**117.3**	**51.3**	**49.6**	**100.9**	**90.8**	**64.3**	**80.0**
SD	5.6	7.0	8.5	8.6	9.8	10.3	2.5	2.8	4.5	4.8	2.4	2.4
Range	*21.0-44.0*	*176.3-201.0*	*95.4-120.1*	*96.0-120.3*	*99.0-131.0*	*101.0-136.0*	*47.1-54.2*	*45.3-54.6*	*94.4-107.6*	*86.0-103.8*	*60.2-66.9*	*76.4-83.5*

Note: All measures are pre-test unless otherwise stated.

Pre-intervention kinematics

A visual example of differences in body position between individual subjects is shown in Figure 9. Descriptive kinematics for all subjects were obtained from the testing session on day one of the experiment, prior to the implementation of the technique intervention. Inter-subject comparisons of these variables (see Table 7) were made to determine the amount of pre-intervention variation present in the study group. For measures of absolute body position the variability over the group was expressed using the coefficients of variation (CV), with an average CV of 13.3%. A CV was considered inappropriate for relative measures, as the variation value would change depending on the point from which the measures were taken. In these cases variability was assessed using the comparison of raw numbers.

Figure 9: Pre-intervention differences in body position during high load backward grinding for subject 5 and subject 7.

Table 7: Numerical description of inter-subject variation in kinematics pre and post the technique intervention for 11 grinders.

	Pre-intervention				**Post-intervention**						
Variable	**Mean**	**SD**	**C.I.**	**C.V.**	**Mean**	**SD**	**C.I.**	**C.V.**	**Change**	**P-value**	**Effect size**
Mean ankle angle (°)	120	9	6.26	7.8%	118	7	4.92	6.2%	-0.5%	0.864	-0.1
Mean knee angle (°)	126	15	10.17	12.0%	111	14	9.65	12.9%	-10.7%	0.052	-0.9
Mean hip angle (°)	101	9	5.78	8.5%	95	6	4.31	6.8%	-6.6%	0.060	-0.9
Mean shoulder angle (°)	44	10	6.85	23.3%	49	7	4.49	13.7%	11.3%	0.208	0.6
Mean elbow angle (°)	134	8	5.62	6.3%	136	7	4.94	5.4%	0.7%	0.777	0.1
Mean trunk angle (°) - from vertical	25	7	5.02	30.3%	17	6	3.71	32.1%	-27.1%	0.028	-1.0
Mean ankle to hip angle (°)	63	5	3.34	7.9%	56	3	1.94	5.1%	-11.6%	0.001	-1.8
Mean ankle to hip distance (m)	0.71	0.07	0.05	10.2%	0.66	0.07	0.05	11.3%	-7.3%	0.127	-0.7
Mean COM$_x$ distance from hub (m)	0.38	0.09	0.06	--	0.42	0.08	0.05	--	0.03 m	0.376	0.4
Mean COM$_y$ distance from hub (m)	0.03	0.09	0.06	--	-0.01	0.09	0.06	--	-0.03 m	0.457	-0.3
Mean hip$_x$ distance from hub (m)	0.53	0.06	0.04	--	0.55	0.04	0.03	--	0.02 m	0.384	0.4
Mean hip$_y$ distance from hub (m)	-0.09	0.07	0.04	--	-0.16	0.06	0.04	--	-0.07 m	0.019	-1.1
Mean shoulder$_x$ distance from hub (m)	0.33	0.07	0.05	--	0.41	0.04	0.03	--	0.07 m	0.013	1.3
Mean shoulder$_y$ distance from hub (m)	0.34	0.06	0.04	--	0.29	0.06	0.04	--	-0.05 m	0.111	-0.7

Technique intervention effects

A number of kinematic as well as performance variables were measured in both pre-intervention and post-intervention testing sessions. All individual subject measures were averaged over the grinder operator's three best-performed trials in a testing session. Kinematic variables were represented by a mean joint angle/position over the course of three full revolutions of the grinding ergometer handles. Summary analyses of pre and post-intervention kinematics from the group as a whole are presented in Tables 7 and 9, while individual responses are detailed in Tables 8 and 10.

It should be noted that while the data from Subject 7 has still been included in the group descriptive results (Table 6), this subject's data were omitted from any results involving post-intervention technique or performance measures. This was due to food poisoning experienced during the intervention week by this subject, which resulted in the subject losing 2.7kg of body mass and being unable to complete all technique practice sessions, along with experiencing additional medical symptoms associated with the illness.

Changes in absolute kinematics

Table 8 shows the analyses of individual subject responses to the technique intervention as expressed by changes in absolute body position. Ankle angle significantly decreased for two of the ten subjects (2 and 8), while only subject 10 showed a significant increase in ankle angle. The knee joint angle, trunk angle, and ankle-hip distance all showed significant decreases in four of the ten subjects, while ankle-hip angle demonstrated a significant decrease in three subjects. Significant increases were seen in the shoulder angle for four subjects (4, 5, 10 and 11) and in the elbow angle only for subject 8. Hip angle was the only absolute variable to not show a significant change in either direction, although there was a trend of decreasing hip angle for eight of the ten subjects.

Table 8: Individual subject trends for pre-intervention to post-intervention measures of absolute body position.

Subject	**Mean ankle angle (°)**	**Mean knee angle (°)**	**Mean hip angle (°)**	**Mean shoulder angle (°)**	**Mean elbow angle (°)**	**Mean trunk angle (°) - from vertical**	**Mean ankle to hip angle (°)**	**Mean ankle to hip distance (m)**
1	↓	↓	↓	↑	↑	↓	↓	↓
2	↓ 🟨	↓ 🟨	↓	↑	↓	↓	↓	↓ 🟨
3	↓	↓	↑	↓	↓	↓	↓	↓
4	↓	↓ 🟨	↓	↑ 🟨	↑	↓	↓	↓ 🟨
5	↑	↓ 🟨	↓	↑ 🟨	↓	↓ 🟨	↓	↓ 🟨
6	↑	↓ 🟨	↓	↑	↑	↓ 🟨	↓ 🟨	↓
7								
8	↓ 🟨	↓	↑	↓	↑ 🟨	↓ 🟨	↑	↓ 🟨
9	↑	↓	↓	↑	↑	↓	↓ 🟨	↓
10	↑ 🟨	↓	↓	↑ 🟨	↑	↓	↓ 🟨	↓
11	↓	↓	↓	↑ 🟨	↑	↓ 🟨	↓	↓
Summary No. significantly ↑ No. significantly ↓	**1** **2**	**0** **4**	**0** **0**	**4** **0**	**1** **0**	**0** **4**	**0** **3**	**0** **4**

↑ = An increase in the measured value from the pre-intervention to the post-intervention test
↓ = A decrease in the measured value from the pre-intervention to the post-intervention test
🟨 = A significant difference (p<0.05) between pre-intervention and post-intervention tests

The trend shown from these individual responses is reflected in the group results, with decreases being shown in all absolute kinematic variables except for the shoulder and elbow angles. When individual data were grouped, significant decreases were seen only in the trunk and ankle to hip angles. With the exception of the standard deviation for the ankle to hip angle all standard deviations and confidence intervals either decreased or remained the same from pre to post-intervention.

Changes in relative kinematics

Trend analyses of changes in relative body kinematics and grinding performance are shown in Table 10. The relative kinematic measures were taken in relation to the crank arm hub at the top of the grinding pedestal on the ergometer. Measures of body position in the horizontal (x) axis showed a significant increase in distance of the body COM from the hub for three of the ten subjects (5, 6, and 10). This was reiterated by a significant increase in relative hip$_x$ position for subject 10 and in relative shoulder$_x$ position for subjects 2, 5, 6, and 11. Vertical (y) axis measures showed a significant lowering of the COM in subject 2 only, with a significant lowering of the hip position in subjects 2, 3, and 5 and a significant lowering of the shoulder position in subjects 2, 5, and 10.

Table 9: Pre-intervention to post-intervention changes in COM and shoulder joint vectors (from grinder hub) and ranges of motion.

	Variable	Pre	Post	Change	Change (%)	P-value
COM	Range$_x$ (cm)	18	18	0.3	1.6%	0.836
	Range$_y$ (cm)	7	6	-1.1	-14.9%	0.360
	Vector magnitude (cm)	47	50	4.0	8.5%	0.429
	Vector angle (°)	4	-2	-6.5	N/A*	0.251
Shoulder	Range$_x$ (cm)	27	28	1.6	5.9%	0.368
	Range$_y$ (cm)	17	15	-2.0	-11.9%	0.347
	Vector magnitude (cm)	67	68	0.7	1.0%	0.654
	Vector angle (°)	47	36	-11.0	-23.4%	0.009

*Note: The calculation of a percentage change is inappropriate when the actual change crosses the value of 0.

Average force vectors (relative to the grinder hub) and ranges of movement (ROM) were calculated as additional descriptors of mean COM and shoulder joint position. When looking at the COM vector, the increase by subject 2 was the only significant change in magnitude, while three subjects showed significant changes in vector angle - decreases for subjects 2 and 5 and an increase for subject 1. Subject 2 had a significant decrease in both magnitude and angle of the shoulder vector, along with a significant decrease in shoulder vector angle from subjects 5 and 11. There were also only two significant changes in ROM, a decrease in COM vertical ROM in subject 1 and an increase in shoulder horizontal ROM and shoulder vertical

ROM for subjects 5 and 2 respectively. The overall trend was for increased horizontal ROM for the COM (six of ten subjects) and shoulder (eight of ten subjects), and a decrease in vertical ROM (seven subjects for COM, eight subjects for shoulder).

The trend from the individual results for relative kinematics was confirmed by the group analysis (Table 9). Horizontal (*x*-axis) measures and vector magnitudes had an increase in distance, while vertical (*y*-axis) measures and vector angle showed a decrease. The only variables to demonstrate significant changes in their respective directions were vertical hip distance from the grinder hub, horizontal shoulder distance from the hub, and shoulder vector angle.

Effects of technique changes on performance

Performance was indicated by power output from a 5-second period of maximal grinding on the grinding ergometer. Analysis of pre-intervention to post-intervention grinding performance (Table 10) revealed an improvement in eight of the ten subjects. Two subjects (2 and 11) had a decrease in power output in the post-intervention test. None of the individual grinding performance improvements or decrements were found to be statistically significant. There was an average 4.7% increase in performance over all eleven subjects with a range of -4.0% (decreased performance) to 15.0% (increased performance) for the pre-intervention to post-intervention changes in power output.

Of the 4.7% ($p = 0.012$) average improvement in grinding performance displayed across the group 2.0% ($p = 0.166$) was explained by changes in the horizontal displacement of COM from the grinding pedestal. The relationship effect was a 0.54% ($p = 0.066$) improvement in performance per centimetre (cm) increase in COM_x distance from the hub. The other main kinematic variable of interest was the hub to shoulder vector angle (pull angle), which was shown to explain only 0.39% ($p = 0.088$) of the group performance improvement with a relationship of 0.03% ($p = 0.840$) increase in performance per degree decrease in pull angle.

Table 10: Individual subject trends for pre-intervention to post-intervention measures of grinding performance, and body kinematics relative to the grinding pedestal.

Subject	Mean COM(X) distance from hub (m)	COM(X) range of movement	Mean COM(Y) position (m)	COM(Y) range of movement	Mean COM vector magnitude (m)	Mean COM vector angle (°)	Mean hip(X) distance from hub (m)	Mean hip(Y) position (m)	Mean shoulder (X) distance from hub (m)	Shoulder(X) range of movement	Mean shoulder (Y) position (m)	Shoulder(Y) range of movement	Mean shoulder vector magnitude (m)	Mean shoulder vector angle (°)	Percentage (%) change in mean work performed
1	↑	↓	↑	🟨 ↓	↓	🟨 ↑	↑	↓	↑	↑	↑	↓	↑	↑	**5.8%**
2	↑	↑	🟨 ↓	↑	🟨 ↑	🟨 ↓	↓	🟨 ↓	🟨 ↑	↑	🟨 ↓	🟨 ↑	🟨 ↓	🟨 ↓	**-1.2%**
3	↑	↑	↓	↓	↑	↓	↓	🟨 ↓	↑	↑	↓	↓	↓	↓	**2.7%**
4	↑	↑	↓	--	↑	↓	↑	↓	↑	↑	↓	↓	↑	↓	**7.8%**
5	🟨 ↑	↑	↓	↓	↑	🟨 ↓	↑	🟨 ↓	🟨 ↑	🟨 ↑	🟨 ↓	↓	↑	🟨 ↓	**4.8%**
6	🟨 ↑	↑	↓	--	↑	↓	↑	↓	🟨 ↑	↑	↓	↓	↓	↓	**3.7%**
7															
8	↓	↓	↑	↓	↑	↑	↓	↓	↑	↑	↑	↓	↑	↓	**3.2%**
9	↑	↓	↓	↓	↑	↓	↑	↓	↑	↓	↓	↓	↑	↓	**10.8%**
10	🟨 ↑	↑	↓	↓	↑	↓	🟨 ↑	↓	↑	↑	🟨 ↓	↑	↑	↓	**15.0%**
11	↑	↓	↓	↓	↑	↓	↑	↓	🟨 ↑	↓	↓	↓	↑	🟨 ↓	**-4.0%**
Summary No. significantly ↑ No. significantly ↓	**3** **0**	**0** **0**	**0** **1**	**0** **1**	**1** **0**	**1** **2**	**1** **0**	**0** **3**	**4** **0**	**1** **0**	**0** **3**	**1** **0**	**0** **1**	**0** **3**	**4.7%**

↑ = An increase in the measured value from the pre-intervention to the post-intervention test

↓ = A decrease in the measured value from the pre-intervention to the post-intervention test

🟨 = A significant difference (*p*<0.05) between pre-intervention and post-intervention tests

Interaction of individual characteristics with technique and performance

Height was shown to have a relationship of 0.29% (p = .225) performance increase per cm of height. When integrated with kinematic variables, height had a similar positive effect. The effect on performance by COM_x increased by 0.12% (p = .249) per SD in height (SD=7.2 cm), while the effect of pull angle increased by 0.06% (p = .465) per height SD. Weight was slightly more effective, with a 0.33% (p = .068) increase in performance per kg of weight and 0.13% (p = .207) and 0.07% (p = .336) increases in performance per SD (8.9 kg) for COM_x and pull angle respectively. Bench pull 1RM had a 0.23% (p = .144) performance increase per kg with a performance increase per SD (10.6 kg) of 0.26% (p = .008) for COM_x and 0.15% (p = .043) for pull angle. Brachial index had the least influence of these variables, with only 0.15% (p = .843) performance increase per 1% increase in brachial index and a performance increase of 0.04% (p = .731) for COM_x and a performance decrease of -0.04% (p = .663) for pull angle per SD (2.5%).

CHAPTER FIVE - DISCUSSION

At the time of this study there was no published research on grinding on an America's Cup class yacht. Grinding is arguably the most physically demanding crewmember activity on the yacht, and is an integral component of a team's overall competition performance (Armitage, 1997).

The present investigation was designed principally to examine the effects of a technique intervention on the power output (the performance measure) and grinding kinematics of America's Cup level grinder operators from the Team New Zealand syndicate. In doing so it was also hoped to increase the general understanding of the human movement mechanics involved in the grinding activity.

Analysis was conducted at both an individual and group level, examining the overall results and trends produced by the technique intervention as well individual responses and possible individual characteristics that may be responsible for such occurrences. Unfortunately, the small number of subjects available for this study (due to confidentiality issues associated with the America's Cup competition), meant that any group analysis was somewhat restricted by a lack of statistical power.

One of the most prominent findings from this study was the amount of individual variation in response to the technique intervention. Although the overall response in terms of performance was positive (an increase in power output), there was a large range of performance change amongst the individuals and the mechanisms for these changes did not always appear to be consistent. It is therefore acknowledged that the eight[12] days available for the intervention training within the team schedule may not have been a sufficient time period for some individuals to correctly learn a new technique.

Inter-subject differences in kinematics

It was observed from pilot testing that a large proportion of the variation in grinding performance under high-load conditions (R^2 of 0.527 and 0.659 for back and forward

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[12] See the "Duration of intervention period" section of Chapter Two - Background.

grinding respectively) could be explained by variation in strength. It was concluded that some of the remaining unexplained variance was due to differences in individual technique, particularly in backward grinding[13]. Therefore one of the aims of this study was to investigate the inter-subject differences in body position (technique) throughout the grinding cycle. The hypothesis was that there would be large differences in pre-intervention body position between subjects. This belief was based on observations from pilot testing sessions, and also on the fact that, prior to this study, knowledge of grinding technique was very limited. An expectation associated with this hypothesis was that following the technique intervention or "coaching" used in this study, inter-subject variation would decrease.

Three measures were used to represent the amount of variation in kinematic variables across the group: the standard deviation, the 95% confidence intervals for the group mean, and where appropriate, the coefficient of variation (%). Coefficient of variation (CV) was used only for the kinematics with absolute measures. A percentage change for the measures taken relative to the grinder hub (COM, hip, and shoulder position variables) was considered inappropriate. That is, while the standard deviation might remain constant, the mean could be altered depending on where the measurement was taken. This is not an issue when comparing the variation in pre-intervention versus post-intervention kinematics, as a within variable comparison of standard deviations and confidence intervals will demonstrate changes in variation. The lack of a standardised variation measure (such as a CV), however, makes identifying the "size" of the pre-intervention variation in kinematics considerably more difficult for the relative measures.

The CV in Table 7 represent the inter-subject variation seen in the pre-intervention absolute kinematics. The kinematics of grinding has not been previously reported so the magnitude of variation for the kinematics of elite grinders was unknown. In the present study it was hypothesised that there would be a large amount of inter-subject variation in kinematics prior to the intervention, however the magnitude of this variation was unknown. While the CV represents a fairly standardised measure of variation, the lack of any comparable research meant that determining what could be considered a "normal" and therefore acceptable amount of variation for the kinematics of grinding. In order to satisfactorily answer the question of what would constitute a large amount of variation the study would have required substantially more subjects than were available. Therefore, the average pre-intervention CV of 13.3±8.7%

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[13] See the "Strength measures" section of Chapter Two - Background for details

for the absolute kinematic variables cannot be accurately classified according to its "size". What can be observed from this figure is that the large standard deviation for the CV shows there were considerable differences in the variation displayed by the kinematic measures, meaning some measures (elbow angle, ankle angle) were inherently more "standardised" than others (trunk angle, shoulder angle). Following the implementation of the technique intervention and its monitored practice sessions there was a decrease in the inter-subject variation demonstrated in ten of the fourteen kinematic measures[14]. Increases in variation measures were seen in the knee angle, trunk angle, and ankle-hip distance, which showed an increase in CV, however, the knee and trunk angles showed a decrease in both the standard deviation and confidence intervals from pre to post-intervention, while ankle-hip distance showed no change in either. Therefore in these instances the increase in CV was entirely the result of a decrease in the mean value for each of these variables. While this does result in an increase in relative variance (as demonstrated by the CV) the absolute variance for a measure - represented by the standard deviation and confidence intervals - has either remained the same or decreased. As the absolute variation represents the actual variability of each kinematic measure the difference in kinematics (technique) between individual grinder operators was effectively decreased as a result of the technique intervention. While individual variation in kinematics was still present, this was unavoidable to a certain extent due to individual variation in anthropometric characteristics. The reduction in variability indicated that the intervention was successful, at least as far as producing changes in individuals grinding technique towards a standardised "target" position.

Technique intervention effects on grinding kinematics

The second aim of this study was to investigate the ability of the intervention to alter grinding kinematics within an eight-day period. Reductions in group variance have indicated that some change was effected through the intervention, but in this section the nature and magnitude of the changes will be discussed. Examining the changes that occurred should address the hypothesis that a technique intervention based on body position could produce a significant change in grinding kinematics.

The changes in kinematics that were expected to occur as a result of the technique intervention were outlined in Table 11. These changes were based on instructions given to

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[14] Change results were as evident at two decimal places.

the grinder operators as part of the intervention, and were aimed at producing the changes in body position as illustrated in Figure 3.

As individual grinder operators demonstrated a variety of pre-intervention body positions, the resulting magnitude of changes was expected to vary between individuals. For instance a grinder operator with a very upright pre-intervention body position (such as subjects 5, 6, and 10) could be expected to make large changes. In contrast, an operator who already employed a low and extended body position, similar to the "target" (subjects 3 and 11), would only be expected to make small changes.

Table 11: The direction of expected kinematic changes resulting from the technique intervention in this study, including a brief explanation of the basis behind these expectations.

Variable	**Expected change**
Ankle angle	Increase (slight): as the body position shifts back from feet ankle angle should increase
Knee angle	Decrease: lowering the trunk position will require increased flexion of the knee
Hip angle	Decrease: lowering the trunk position will require increased flexion of the hip
Ankle-hip angle	Decrease: the ankle remains at same level but hip is lowered with the trunk position
Ankle-hip distance	Decrease: due to increased knee flexion the hip is closer to ankle
Shoulder angle	Increase: as the body is moved back from the pedestal shoulder extension must increase
Elbow angle	Increase: as the body is moved back from the pedestal elbow extension must increase
Trunk angle - from vertical	Decrease: trunk position should become more upright as body position is moved back
COM position	Should get further back from the pedestal (x increase) and lower (y decrease)
COM vector	Increased magnitude and decrease in angle as the body position is lowered and moved back
COM movement range	Increase in x-axis but decrease in y-axis as the main pull direction becomes more horizontal
Hip position	Should get further back from the pedestal (x increase) and lower (y decrease)
Shoulder position	Should get further back from the pedestal (x increase) and lower (y decrease)
Shoulder vector	Increased magnitude and decrease in angle as the body position is lowered and moved back
Shoulder movement range	Increase in x-axis but decrease in y-axis as the main pull direction becomes more horizontal

Changes in absolute kinematics

One of the most encouraging aspects of the intervention, in terms of its apparent effectiveness, was that the changes generally tended to occur in the same direction. Of the absolute kinematic variables measured, all (excluding the ankle angle) registered changes in the direction predicted (see Table 11) for seven or more of the ten grinder operators included in the final analysis. A decrease in ankle angle was seen in six of the ten subjects, which made ankle angle the weakest absolute kinematic variable in terms of change consistency. The decreases seen in angle at the ankle also opposed the expected change. An expected increase in ankle angle was based on the premise that when the body moved back and away from the pedestal, so would the position of the knee joint. This should have resulted in the ankle joint moving into a more plantarflexed position, however, this outcome relied on the assumption that the feet would remain in the same place from pre to post-intervention. As no specific instruction was given to the grinder operators regarding the placement of their feet, and given the outcome presented here, it is apparent that this was an invalid assumption. Fortunately, the placement of the feet and the ankle angle should not have had any substantial effect on the performance of the grinding activity. This is because the contribution of the shank, ankle joint and the associated muscles of the ankle would be minimal in grinding. In such an activity, their main function is to provide an appropriate balance point for the body. Maintaining this balance point may in fact have been aided by a lack of instruction regarding foot placement, as depending on the change in position of their body, each individual will have been able to adjust their foot placement according to what felt most comfortable/stable.

It was hypothesised that the technique intervention would produce significant changes in kinematics, however, group analysis only resulted in statistically significant changes for two of the eight absolute kinematic variables measured - trunk angle and ankle-hip angle. A likely influencing factor in the low number of significant changes found using group analyses were the small subject numbers in this study. The consequence of this is that while group analyses are still very useful for identifying general trends in responses, poor statistical power reduces the likelihood of obtaining significant results. It is interesting that the two absolute kinematic variables which showed the least response (the elbow and ankle angles), were also those with the least association with the instructions given (predominantly directed at the positioning of the shoulder and hip joints). This suggests that the instructions given were successful in creating a change in the areas intended. An additional factor could be the ability for these variables to be changed from the pre-intervention technique. The interaction between ankle angle and foot placement has already been discussed, but the possible reason for a lack of change in elbow angle has not been discussed.

It was predicted that mean elbow angle should increase as a result of the shoulder joint being moved further back from the grinder hub to increase the functional arm length (a movement which requires greater extension of the both the elbow and shoulder joints). Although elbow angle did increase in seven out of ten subjects, there was only a significant change in one grinder operator (subject 8). It should also be noted that, as the average change over the entire group was only two degrees, the change could be due to digitising error. Since the indications have generally been that instructions were followed well, this lack of any real change suggests that the scope for further extension of the elbow during the grinding cycle is minimal. The elbow may already have been at almost full extension whilst still maintaining grip on the grinder handles throughout the entire cycle. This theory is also supported by the lack of change exhibited in the magnitude of the hub to shoulder vector, which represents the actual distance between these two points. Based on the same reasoning as for the elbow joint angle, the hub to shoulder vector was expected to increase, however, although seven subjects showed an increase none were significant, a result reflected in the group analysis where the magnitude of the shoulder vector only increased by 1 cm (p = .654). In addition, as the mean shoulder vector magnitude was 67 cm (pre-intervention) and the mean total arm length for the subject group was 64 cm (acromion process to the styloid process of radius) it seems safe to assume that full extension was reached. The greater distance of the shoulder vector magnitude in this comparison was possible due to the exclusion of the hand from the "total arm length" measurement, so the actual reach was slightly longer than the total arm length measure.

It has been established that the overall extension of the arm did not increase as a result of the intervention. It must then be explained why the angle at the shoulder joint increased (average of 11.3% across the group) in eight of the ten grinder operators (significantly in four). The instructions given to the grinder operators were aimed at levelling the shoulder joint with the apex of the grinder handle arc, and shifting the COM as far back from the grinding pedestal as possible. For most of the subjects this resulted in the trunk being moved down and away from the grinding pedestal. One of the results of this was that the angle between the arm and the trunk opened up, which is represented by the increase in shoulder angle (see Figure 10). Although the distance from the hub to the shoulder joint remains the same, this increased extension at the shoulder is actually increasing the distance between the grinder hub and the grinder operator’s COM by enabling the trunk to be moved further away. The distance from the grinder hub to the operator’s COM represents the effective lever arm and lengthening this distance should increase the torque applied to the handles.

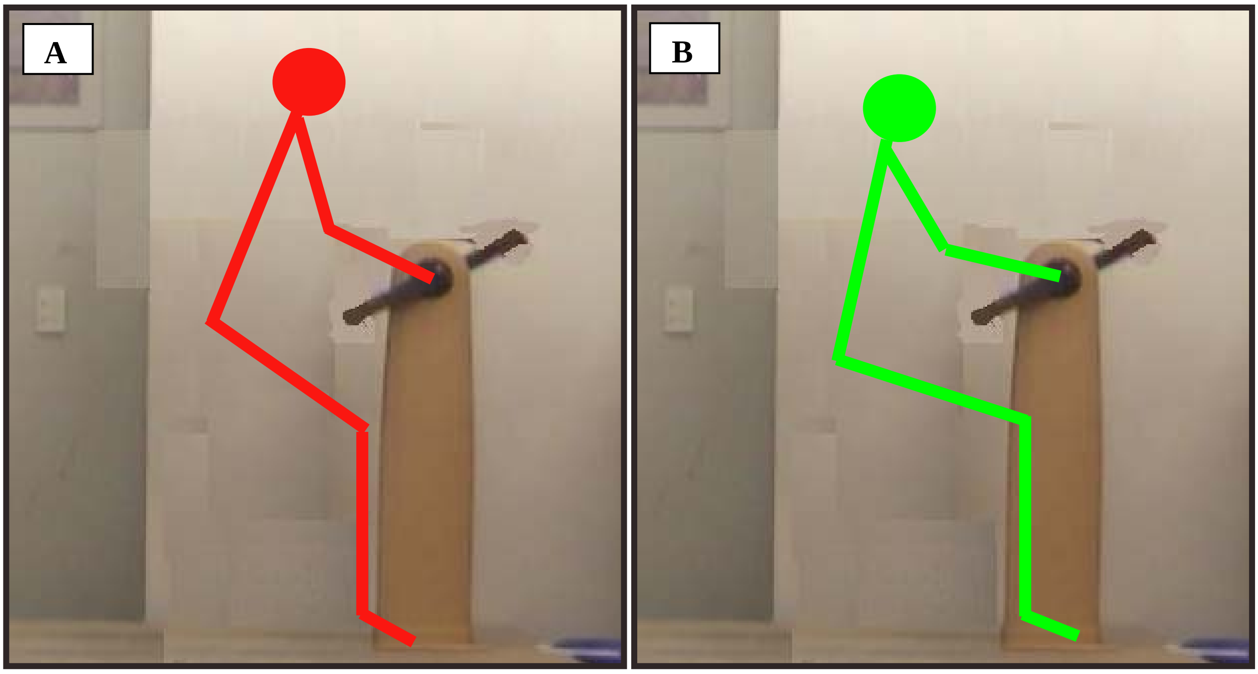

Figure 10: Visual representation of the "actual" change in the average group body position from pre-intervention (A) to post-intervention (B). Note: This is the average body position for the entire cycle, therefore the hands are located on the hub - the average position of the handles.

One of the main focal points for the grinder operators during the practice sessions was the position of the hip joint. The reason for choosing the hip joint was that in most cases it has a close association with the body's COM, but is an easily identifiable visual landmark. The instructions generally focused on getting the hip marker lower down (lowering the trunk and shoulder and therefore flattening out the angle of pull) and further back from the grinding pedestal (increasing the effective lever arm). The expectation was that this change would be reflected in a number of the absolute kinematic variables measured, specifically a decrease in the knee angle and ankle-hip angle, along with a decrease in ankle-hip distance. The decrease in knee angle, representing increased flexion, is the only functional method of lowering the position of the hip while still maintaining stability and support for the body. Accordingly, all ten of the grinder operators exhibited a decrease in knee flexion, four of which were significant. An identical result was seen in the decrease of ankle-hip distance, which is not at all surprising as Pythagoras’ theorem ($a^2+b^2=c^2$) dictates that this should occur due to the ankle-hip distance being merely the opposing side of a triangle based around the knee angle. Ankle-hip angle provides additional information compared to the knee angle alone. A decrease in the angle between the ankle and hip indicates not only a decrease in height of the hip joint, but also a change in the horizontal distance between the ankle and hip. For instance it would be possible to lower the hip without changing the ankle-hip angle if the decrease in vertical height of the hip joint was matched by a decrease in the horizontal distance between the ankle and hip joints. Although lowering the body may be considered beneficial, the detrimental effect of a reduced effective lever arm length would be of comparatively greater detriment, which might have an overall negative effect. Therefore, a decrease in ankle-hip angle is reflective of an increase in the hip_x position:hip_y position ratio. This indicates that the horizontal distance of the hip from the ankle has become relatively greater than the vertical distance of the hip from the ground – which would be viewed as a positive occurrence. Demonstrating that the technique intervention produced this result, nine of the ten subjects exhibited a decrease of ankle-hip angle, three significantly.

The interaction between the changes made in the position of the shoulder relative to those made at the hip/lower limb are described by the trunk angle and hip angle variables. One of the main focuses was getting the COM back from the grinding pedestal and therefore increasing the lever arm however, there was also a trade-off with the need to maintain appropriate balance, enabling the effective application of the force to the grinder handles. Whilst the distance of the shoulder joint from the pedestal was constrained to 60-70 cm by the need to maintain a grip on the grinder handles, it was possible to place the feet up to 1-1.5 m away from the pedestal. Due to the large amount of total body weight contained in the lower limb[15], a manoeuvre such as this could produce a significant backwards shift in the COM. It does, however, considerably limit how the body weight – represented by the COM – may be applied to the pulling movement required in backward grinding. This is due to the body’s pivot point for grinding – represented by the feet – being located behind the COM. As a result the application of body weight can only be directed toward the grinding pedestal; useful for a “push” action as in forward grinding, but not at all beneficial for the “pull” action of backward grinding. The pivot point therefore, needs to be forward of the COM, meaning the body weight is directed back and away from the grinder handles. Having the feet placed further forward will require increased hip flexion (decrease in hip angle) and the hips will

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[15] See: p21 “Force production” (Chapter Two - Background) for details.

also be drawn forward. Assuming the arms remain extended – which has been shown to be the case – this will result in a decreased trunk angle, meaning the trunk will be more upright. Trunk angle also acts as an indicator for vertical body position, which must be lowered in order to attain the more horizontal pull angle desired. Because of the previously mentioned constraint on the distance the shoulder can diverge from the grinder handles, the higher the body position employed, the greater the forward lean of the trunk, which will increase the horizontal distance between the hip and the shoulder. Therefore, a lower body position will decrease this distance, resulting in a more upright trunk and reduced trunk angle. The intervention for this study produced changes in both hip angle and trunk angle for most grinder operators in the manner described above. A decrease in trunk angle was shown in all ten subjects and a decreased hip angle in eight.

Changes in relative kinematics

While the changes in absolute kinematics were encouraging in their generally compliant response to the intervention, they only really provided a description of the position of the grinder operator's body. What makes the real difference to grinding performance is the arrangement of the body relative to the grinding pedestal. The absolute kinematics are the mechanism for producing the change, but the relative kinematics are the end result – in a sense representing the sum of the changes seen in the general body position. The measures taken to help describe relative body placement were positional measures of the shoulder joint, hip joint, and the COM relative to the grinder hub. The hub was chosen as the reference point due to its centrality to the action of grinding. As the point around which the grinder crank arms and handles rotate, the hub represents the average position of the handles (in both the horizontal and vertical axes) throughout the entire grinding cycle. Once again, the changes exhibited in the group analyses were almost all in the direction predicted, the one exception being the COM_x range of movement, which showed no change. As with the absolute kinematics, very few of the measures taken showed a statistically significant change, with only three of the 14 relative kinematic variables (hip_y position, shoulder_x position, and shoulder vector angle) attaining the required statistical significance level ($p<0.05$). It appears likely that the main reason for not attaining statistically significant changes for more of the variables lies in the low subject numbers available for this study.

One of the central ideas for improving grinding performance was to shift the grinder operator’s COM further away from the hub, increasing the effective lever arm and improving the application of torque at the handles. The COM represents the average position of the grinder operator's entire body, taking into account location and estimated mass (de Leva, 1996) of all the segments. This is best represented by the change in the horizontal distance of the COM (COM_x) from the grinder hub. If the intervention was successful in producing kinematic changes it was expected that an increase in the COM_x distance would occur - a result that was seen in nine of the ten subjects (three significant). The extension of the COM to pedestal distance was also reflected in increases in the $shoulder_x$ and hip_x positional variables, which were shown to increase in ten (four significant) and seven (one significant) of the grinder operators respectively. It is interesting to note the relatively greater "success" of these changes at the shoulder joint compared to those at the hip. While the hip position moved back from the pedestal in most cases, the changes were usually small. This suggests that the original hip position was already well back, and that the more forward position of the COM in the pre-intervention technique was due mainly to the shoulder position and associated forward lean of the trunk. Assuming this is true, then the increases in COM_x distance from the hub will have been attributed to the extension of distance at the shoulder, rather than the corresponding increase at the hip. Therefore, the backwards shift in the COM location would mainly have been obtained through the lowering the body position and the shoulder position being rotated backwards and down making it more vertically aligned with the hip position[16].

The second aim for improving grinding performance was to flatten the main angle of pull for backward grinding movement. This should increase the possible body weight contribution to the pull in addition to reducing the detrimental effects of gravity. When grinding backward the majority of the grinder operators stood quite erect prior to this study so, therefore, the intervention aimed to lower their body position, which also assisted by increasing the distance from the hub to the COM. As the angle of pull was determined by the position of the shoulder relative to the handles, a vector was calculated from the grinder hub to the average shoulder position, with the grinder hub representing the average position of the handles throughout an entire grinding cycle. Pilot work for this study, however, suggested that the main pull phase occurs almost entirely through the upper half of the cycle (although this varied with body position). It is therefore acknowledged that the vector angle calculated from the hub is only an approximation of the angle of pull. A more realistic representation

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[16] See the section "Changes in absolute kinematics", p61 regarding trunk angle.

could be made if the “start point” (replacing the hub) for the vector were placed higher. Because of the potential variations in the actual start point (due to differences in body position) the hub was retained in order to preserve the consistency and repeatability of the measurement. Consequently, the angle of pull was represented by the angle of the hub to shoulder vector. Prior to the intervention the shoulder vector angle reached values of up to 62° (subject 6), but with the intervention it was anticipated that this could be reduced in most of the grinder operators. As was mentioned previously, shoulder vector angle was one of the relatively few variables to show a significant change in the group analyses, with an 11° (p = .009) decrease (-23%). This decrease was due to changes in both the vertical and horizontal position of the shoulder joint. As with the ankle-hip angle[17] the hub to shoulder vector angle was a measure of the relative x and y-axis positions of the joint in question. Therefore, because the shoulder joint is located above the hub, a decrease in shoulder vector angle/angle of pull can be produced equally by an increase in shoulder_x position or a decrease in shoulder_y position. Of the ten subjects used, nine showed a decrease in shoulder vector angle (three were significant), the only exception was subject 1 whose results will be discussed later[18]. In terms of compliance to instruction this result is very positive. Instructions for the grinder operators to lower their body position appear to have been followed very well as in addition to the results already discussed, both the shoulder_y position and hip_y position showed substantial changes in the direction desired.

One of the additional factors expected to change, as a result of the intervention, was the general efficiency of the backward grinding movement. Along with the desired performance gains it was also anticipated that the intervention would put the grinder operators in a more stable position where expenditure of energy through extraneous movements would be minimised. Lowering the body position so that the main pull movement occurred in a predominantly horizontal plane would mean that movement in the vertical (y) axis – where gravity becomes a factor – would be minimised. The average displacement (range of movement) of the shoulder joint and COM throughout a grinding cycle was measured to quantify this occurrence. The theory was that with the technique intervention the range of movement in the x-axis would increase, and range of movement in the y-axis would decrease. While the majority of individuals did exhibit such changes, only two significant results were

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[17] Discussion of ankle to hip angle is in “Changes in absolute kinematics”, p65.

[18] See: “Non-uniform changes in kinematics” for further discussion

recorded; decrease in COM_y range of movement for subject 2 and an increase in shoulder_x range of movement for subject 5. Unfortunately, subject 2 also showed a significant increase in shoulder_y range of movement, in the opposite direction to that expected. Overall, the group changes in range of movement, at least for the shoulder and COM, were minimal.

Non-uniform changes in kinematics

Although the technique intervention used in this study succeeded in creating kinematic changes in the predicted directions, as with most studies, there was a certain amount of individual variation. Some individuals responded better than others, and unfortunately some of the grinder operators exhibited changes in the opposite direction to what was desired. Taking into account all of the kinematic variables measured and the number of subjects used in this analysis there were 210 responses, of which 32 were non-uniform, that is: they occurred in the opposite direction to those desired/expected. These figures do not include ankle angle due to the high dependence of this measure on foot placement; a variable unconstrained by either attachment to another segment or any technique instruction[19].

Of the non-uniform kinematic results a large number can probably be classed as effectively being a "no-change" response. Because of the inherent variability in this kind of testing, combined with the additional digitising error from the video analysis used to obtain the results (Appendix 5), any change in a kinematic measure of less than 5% was classed as unsubstantial, or a possible "no-change" response. The classification of a no change response will also apply to results occurring in the desired direction, and consequently the discussion of these changes has tried to focus on group trends rather than individual cases as much as possible. Assuming that this classification of "no-change" responses is valid (with "no-change" being not ideal but acceptable) then the number of substantial non-uniform results is reduced to 19, three of which were significantly non-uniform. Details of the responses from these subjects can be found in Appendix 9. The four remaining substantially non-uniform results occurred two apiece in subjects 9 and 11, and in both cases the variables in question were the shoulder_x range of movement and the COM_x range of movement. Each of these responses exhibited a decrease in range of movement, rather than the expected increase. Aside from the fact that the shoulder_x and the COM_x range of movement variables will be linked there is no apparent explanation for why these anomalies occurred. With the

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[19] See: "Changes in absolute kinematics" p58 for background to this comment.

exception of these two range of movement variables, both subjects 9 and 11 demonstrated changes in kinematics exactly as predicted, making the explanation of these results rather difficult.

Effects of grinding technique changes on grinding performance

The third aim of this study was to determine the effect of altering technique on grinding performance. It was hypothesised that altering grinding technique could produce significant changes in performance. Performance was measured using the power output from the grinding ergometer, represented as total work (kJ) performed over five seconds from the occurrence of maximum power during a maximal effort trial. By comparing the differences in work performed (kJ) and grinding kinematics from pre to post-intervention tests it was hoped to identify whether any real change in performance had occurred, and if so what where the actual mechanisms behind the change.

As has been previously identified, one of the major determinants of overall grinding performance was an individual's strength, especially under high load conditions[20]. As strength was so strongly related (a correlation of 0.726, $p<0.000$ for backward grinding) it was important to check that any reported changes in performance were due to the technique intervention and not to a coinciding change in strength. It was hypothesised that due to the relatively short duration of the intervention period (seven days between pre and post-intervention measures) there would be no significant changes in strength over that time. Individual 1RM bench pull scores were taken from strength testing sessions conducted on the morning of both the pre-intervention and post-intervention tests. The mean 1RM for the group changed from 116.4 ± 9.8 kg (range 99-131 kg) for the pre-intervention test to 117.3 ± 10.3 kg (range 101-136 kg) for the post-intervention test. The pre and post-intervention test values were strongly correlated ($r=0.968$, $p<0.01$), and were not significantly different ($p = .834$). This result supported the hypothesis that no significant changes in strength would occur over the intervention period, however, it is acknowledged that the variability in the 1RM scores obtained at each test means that the possibility does exist for significant changes in strength occurring at an individual level, although a certain amount of variation should be expected as a normal occurrence. Even assuming the changes seen in strength were real as opposed to normal variation of the testing procedure, the two grinder operators who showed

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[20] See: “Interaction between muscular strength and grinding performance” (Chapter Two - Background).

the greatest improvement in strength (subject 3 = 4.4% and subject 8 = 3.8%) only showed fairly small improvements in grinding performance (2.7% and 3.2% respectively). These are both reasonably well below the average change in performance, which was 4.7%. This supports the position that strength was not a significant factor in the grinding performance improvements seen in this study. If it were subjects 3 and 8 would have been expected to be two of the biggest improvers rather than two of the lowest.

A significant change in power output over the five-second period (4.7%, $p = .012$) was produced by the intervention. This result confirms that the technique intervention was effective in improving grinding performance, as the possibility of a change of that magnitude occurring by chance is minimal. A 5% performance improvement in elite-level physical competition is generally considered to be a substantial increase. In grinding a 5% increase in grinding power output would allow the sails to be positioned correctly in a shorter time in order to maximise wind usage. A decrease in the time spent correctly positioning the sails will also allow the boat to gain an advantage by reducing the detrimental effects of lost boat speed associated with tacking or gybing. While grinding is not the only determining factor in the performance of an America's Cup, this does give an indication of the difference a change of the magnitude seen here can make in a competition setting. While the average performance change was a 4.7% increase, individually the results varied from a 4.0% decrease in performance (subject 11) to a 15.0% increase in performance (subject 10). Unfortunately none of the individual changes were statistically significant, which was unusual given the percentage changes for some grinders. As with most sporting activities there will be a certain amount of natural performance variation from day to day, with the results from pilot testing suggesting that this variation is 2-3%. Change scores of less than this should therefore be interpreted with caution, although given that eight of the ten grinder operators who completed the study showed changes of over 3% and some improved by over 10%, it seems unusual that no statistically significant changes occurred. The most likely explanation for this is related to the number of trials analysed for power output. Whilst four trials were conducted at each testing session the first two trials performed were excluded from power output analysis[21]. The lack of statistical significance obtained from individuals indicates that the number of trials analysed was probably too low. Therefore it seems that ideally the number of trials conducted should have been greater in order to improve the statistical power of the measures. Future studies should use larger numbers of subjects and

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[21] See: “Number of trials” (Chapter Two - Background) for justification.

larger numbers of trials. Future studies should also try to determine the actual mechanisms behind the changes seen.

The horizontal (*x*) distance between the grinding pedestal/hub and the COM was expected to have an influence on grinding performance. The distance between the COM (average position of the entire body) and the grinder hub (average position of the handles) represents the length of the effective lever arm for the body weight to affect the force at the handles. Increasing this distance should improve the ability of the body weight to affect the rotation of the handles and therefore improve power output/performance. The effect of COM_x position was confirmed when the relationship between the changes in performance and the changes in COM_x position for this study were analysed. Following the technique intervention the average performance change for the group was a 4.7% increase. This value represents the absolute, unexplained difference in power output between the pre-intervention and post-intervention testing sessions. When COM_x position and the changes exhibited during the intervention were taken into account, however, this figure was reduced to 2.7%, meaning that COM_x position explained about 40% of the change in performance. The actual relationship between the two measures was shown to be a 0.54% improvement in performance for every centimetre increase in COM_x distance from the hub. This represents a decent effect for one variable, although possibly not as great as would have been hoped. Over half of the improvement in backward grinding performance brought about by the technique intervention in this study still remains unexplained.

The second kinematic variable thought likely to have an effect on grinding performance was the angle of pull, represented in this study by the vector angle from the grinder hub to the average position of the grinder operator’s shoulder. By decreasing the angle of pull it was thought that the proportion of the total body weight contributing to the movement would be increased. In addition, any adverse effects of gravity would be decreased as the main pull phase became more horizontal. Adding shoulder vector angle into the model reduced the unexplained effect of the intervention from 4.7% to 4.3%, an explanation of only about 8% of the performance change. Accordingly, the relationship was not very strong either, showing a 0.03% increase in performance for every 1° decrease in shoulder vector angle. This corresponded to a performance increase of 0.2% for a one standard deviation decrease in shoulder vector angle (7.8°). This was an unexpected result, as pull angle was expected to have had a substantial influence on performance and its apparent effect from this analysis was negligible. It is possible that this result was partially due to how well the hub to shoulder vector angle actually represented the angle of pull. As was mentioned earlier[22] the actual line of pull would be flatter than that calculated in this study due to the main pull phase being executed predominantly through the upper part of the handle rotation, rather than all the way around - as is actually represented by the hub. However, either way the "start" point should have remained constant, with the changes in pull angle coming from the change in shoulder position and therefore, while the actual values would have been different, the changes in angle produced by the intervention and a shift in shoulder position should have been satisfactorily represented by either method. Unfortunately, the pull angle (or the shoulder vector angle measurement) does not appear to have any strong effect on heavy load, backward grinding performance.

The one grinder operator who has so far been an exception to all of the analyses conducted was subject 11, who demonstrated a 4.0% decrease in performance following the technique intervention. Subject 11 showed no potentially negative changes in kinematics that could have explained the performance decrement. The only changes exhibited in the opposite direction to what was intended were decreases in COM_x range of movement and $\mathrm{shoulder}_x$ range of movement, although the changes seen in the range of movement variables have been generally unreliable and should not have had a noticeable affect on performance. A possible explanation for this occurrence is related to the relative experience of the grinder operators. At 44 years of age, subject 11 was substantially older than any of the other participants and as a result had close to 10 years more experience in grinding (20+ years in total). Such experience means that the backward grinding technique subject 11 had been using prior to the intervention will have been extremely well in-grained, and as a result having to re-learn a new technique was likely to have been much more difficult than for a grinder operator of lesser experience. Therefore an intervention of eight days may not have been sufficient for subject 11 to successfully adopt the new technique.

Interaction of individual characteristics with technique and performance

As well as the effect that kinematic changes can make to performance, it is also acknowledged that the characteristics of an individual may affect their performance. There may be some characteristics that can help determine whether an individual will be good at grinding. One example of this sort of relationship has already been shown in the case of strength and high resistance grinding. It may also be that with changes in technique - such as those advocated in this study - certain characteristics can mediate how effective the technique changes will be in altering performance. Characteristics thought most likely to have an influence on grinding performance and technique were body weight, standing height, strength, and brachial index. The interaction between these individual characteristics and technique was examined using the COM_x position and pull angle (hub to shoulder vector angle) variables. These two kinematic variables were thought to provide the best representation of the desired changes from the technique intervention.

Body weight figured prominently in the design of the technique intervention, with both the increase of the COM to pedestal distance and decrease in pull angle intended, at least in part, to improve the contribution of body weight to the main pull phase. It was therefore expected that increased body weight would be beneficial to high load backward grinding performance. An examination of this relationship showed a performance increase of 0.33% (p = .068) for every kilogram of body weight above the mean (2.9% change per SD). For example, this means that in theory subject 5 (110kg) would be expected, theoretically, to perform 3.5% better then subject 1 (99kg) on the basis of body weight alone. However, as body weight will not be the only factor that affects grinding performance, the actual difference should vary from this value. Body weight also showed a positive relationship with the effect of technique changes, as represented by COM_x position and pull angle. Body weight was seen to produce an additional performance improvement of 0.13% (p = .207) and 0.07% (p = .336) per SD (8.9 kg) for COM_x and pull angle respectively. Therefore, a grinder operator of average body weight (104 kg) could expect approximately a 2.2% improvement in performance from an average change in COM_x position (4 cm). In comparison, a grinder operator who was 1 SD heavier than the average (113 kg) would expect a 2.7% improvement under the same conditions, assuming that there are no other influencing factors. A similar outcome could be seen for changes in pull angle, although the difference created by body weight would not be as great. While these effects are not particularly large or statistically significant these results do indicate that increased body weight has a positive influence on the effect of the technique intervention. This relationship was expected because the changes in COM_x position and pull angle were intended to improve the influence of body weight on the grinding movement, and

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[22] See: "Changes in relative kinematics"

body weight has been shown to have a reasonable strong and positive relationship with grinding performance. Therefore any improvement in performance brought about by a change in the influence of body weight should be exaggerated with greater body weight.

Height was also expected to have a positive relationship with high load backward grinding performance. This was based on the notion that getting the COM of the body further away from the grinding pedestal and increasing the effective lever arm will be beneficial to performance. Therefore, a tall individual with relatively longer limbs would be able to attain a greater COM distance, a longer effective lever arm, and better performance than a shorter person. This theory was supported by the analysis from this study, which showed a 0.29% ($p = .225$) increase in performance per centimetre increase in height (2.1% change per SD). The influence of height on kinematic changes was of a similar magnitude to body weight, and likewise lacked statistical significance. The effect on a one centimetre increase in COM_x was an additional increase of 0.12% ($p = .249$) in grinding performance per SD in height (SD = 7.2 cm). Meanwhile, the effect of a one degree decrease in pull angle was an increase of 0.06% ($p = .465$) in grinding performance per SD in height. This relationship can be explained by looking at the underlying reason for reducing pull angle. That is, by decreasing the angle of pull there should be a decrease in the detrimental effects of gravity on the pull phase. Consequently, the effectiveness of any individual characteristic that contributes to performance (such as height) would therefore be increased. However, the similarity between the influence on COM_x change by height and by weight was unexpected. Since the optimisation of body weight usage was a substantial factor in the desired increase in COM_x, body weight could be expected to influence how effective kinematic changes would be, however, no such theory was associated with height. It is possible that the influence of height is the result of the close relationship between height and weight (R = 0.765, $p = .006$), rather than due to height itself. As a consequence, the influence of weight on the effectiveness of changes in COM_x position may also be reflected when examining the influence of height. This theory is supported by the effect values displayed by the two individual characteristic variables, with the influence of height being both slightly smaller (0.13% versus 0.12%) and slightly less significant ($p = .249$ versus $p = .207$) than the influence of weight. This sort of decrease in the size and strength of the influence is what would be expected in a strongly related variable showing an effect through association rather than having an actual effect of its own.

Maximal strength has already been shown in pilot testing to have a strong relationship with high load grinding performance. This result was supported by the post-intervention analyses which showed that a linear relationship between predicted bench pull 1RM (the strength measure for this study) and high load backward grinding performance with a 0.23% (p = .144) performance increase per kilogram of bench pull 1RM (2.4% change per SD). While this result was not as conclusive as the pilot study analyses ($p<0.001$) it does demonstrate a substantial relationship between the 1RM bench pull and high load backward grinding performance. The influence of strength on the effectiveness of kinematic changes was much more encouraging. A 1 SD (10.6 kg) increase in 1RM bench pull score produced an additional performance benefit of 0.26% (p = .008) per centimetre increase in COM_x, and of 0.15% (p = .043) per degree decrease in pull angle. In addition to having the largest influence on the effectiveness of any of the four individual characteristic variables examined, these two strength-related results were also the relationships obtain statistical significance. As it was with height, the relationship between strength and pull angle was consistent with the belief that a lowered pull angle should result in the increased effectiveness of an influencing variable. The additional size and statistical strength of this influence is probably the effect that a decrease in pull angle has on the angle of the shoulder joint. The lowering of the shoulder joint generally required when decreasing the angle of pull will result in an increased angle at the shoulder, putting the muscles used in the main pulling into a more optimum position for creating force. Strength curves for shoulder extension in males have been shown to peak at 90-100° (Williams and Stutzmann, 1959; Campney and Wehr, 1965) with force declining as the angle increases or decreases. Since the increase in shoulder angle seen in this study brought the shoulder angle closer to 90° this can be expected to improve the muscular force production. Therefore, stronger individuals will benefit more from an increase in muscular efficiency brought about by the decrease in pull angle. A similar principle is likely to be responsible for the influence of strength on COM_x effectiveness. Moving the COM_x position back will also contribute to the increased shoulder angle just described with relation to angle of pull. Therefore, the effectiveness of a change in COM_x position will also benefit from greater strength. Moving the COM_x position further back will also put the muscles across the back of the shoulder joint (those primarily responsible for the main pulling movement) into a greater state of stretch. As grinding is a rapid movement even under the high loads used in this study (reaching 80+ rpm) the slight increase in the pre-stretch of the shoulder extensor muscles should increase the contribution of the muscular stretch-shorten cycle to the force of the muscular contraction. In a study involving upper body movements Wilson, Elliott, and Wood (1992) showed increased pre-stretch (in their case due to flexibility training) to improve muscular performance in the rebound bench press activity. Again, the benefits from the improved muscular performance will be relatively greater for a stronger individual, and the combined benefits of the angle at the shoulder and the stretch-shorten cycle would result in the strong influence as shown in this study.

The least effective of the four individual characteristic variables assessed in this study was brachial index. It was assumed that a higher brachial index, representing a relatively shorter upper arm (humerus) compared to the forearm, would be more efficient for the pulling movements that dominate backward grinding. In actuality, however, the relationship was only shown to be a 0.15% (p = .843) increase in performance per 1% increase in brachial index (0.4% change per SD). Put into context, this would result in a performance difference of less than 1% between the grinder operator with the lowest brachial index (subject 8) and the grinder operator with the highest brachial index (subject 1). It is likely that brachial index may not make that much of a difference, as unfortunately the high *p*-value indicates that it is more likely that a relationship of that size occurred by chance. This lack of any substantial relationship is probably due to the difference in movement mechanics between backward grinding and rowing - the activity on which this brachial index theory was based. Both activities start their pull phase with the arm fully extended. In rowing the hand is then pulled in towards the body with the pull phase only finishing when the elbows are almost fully flexed and the base of the thumbs are in contact with the lower ribs (Herberger, 1990). In comparison the pull phase of the backward grinding cycle is discontinued much further out from the body. As a result a considerably smaller proportion of the pull phase is conducted with the elbows in flexion during backward grinding than in rowing, somewhat negating the potential benefits of a higher brachial index. It could therefore be hypothesised that, although the effect may still not be great, a grinder operator with shorter arms would benefit more from a high brachial index than a grinder operator with longer arms. This is because the crank arm length remains constant, and therefore the grinder operator with shorter arms would be spending relatively more time in elbow flexion. It is also possible that a relationship between backward grinding performance and brachial index does in fact exist, but does not show up because of the homogeneity of the sample used. If a high brachial index were a necessary characteristic for a well successful grinder operator, then the subject group used in this study would have already been pre-selected by that variable. For this to be successfully determined it would therefore have been necessary to include a group of non-grinders in the study. In terms of the interaction with kinematic changes, one standard deviation in brachial index (SD=2.5%) showed a 0.04% (*p* = .731) increase in performance for every centimetre increase in COM$_x$, and a performance decrease of -0.04% (*p* = .663) for every degree change in pull angle. These contradictory results tend to support the suggestion made here that brachial index had no real effect on the performance of high load backward grinding.

Overview

In summary, the four hypotheses stated for this study were all at least partially supported. There were moderate differences in pre-intervention body position between subjects during backward grinding. There were some statistically significant changes and a number of substantial changes in kinematics of backward grinding with the technique intervention based on body position. Altering grinding technique according to biomechanical principles did produce a significant change in the amount of power produced against a given load for the subject group used. There was no significant change in strength, measured with 1RM, over the eight-day intervention programme.

Practical application

The technique advocated in this study was shown to be effective in improving performance on a land-based grinding ergometer, therefore it was recommended that the Team New Zealand America's Cup syndicate should try and employ the technique during on-water grinding. Feedback from Team New Zealand regarding the employment of the technique has been positive. The estimation of relative usage in certain race conditions has been that the most effective and most prevalent application of the new technique occurs when sailing downwind, and in particular when grinding the spinnaker pole back (~90% of total usage). The rest of the usage tends to occur at the end of an upwind tack, when heavy loads come on the grinding winches. The common factor between these two conditions are that they both involve very heavy load at the grinding winches, making the additional force application at the handles gained from this technique much more valuable than at low loads. It should be noted that the much higher usage in downwind conditions has a lot to do with the heel (sideways lean) on the boat. Due to the construction of the grinding ergometer, all the testing used in this study was conducted on a flat platform. This transfers well to downwind sailing where the deck remains reasonably flat, but when sailing upwind the deck will almost always have significant heel, making the foot placement involved considerably more difficult. However, despite some complications between land-based and on-water implementations, the principles involved in the trialed technique are applied as often as possible on the boat. Most gratifyingly, the general feedback has been that the grinding performance of the Team New Zealand America's Cup syndicate has benefited from this study. However, the true benefit of the grinding technique intervention can only be assessed by kinematic analysis and power output measurement on the boat.

CHAPTER SIX – SUMMARY

The grinding technique intervention used in this study was successful in producing an average and significant 4.7% ($p = 0.012$) increase in power output across the whole group of grinders, with individuals improving by up to 15.0%. During the eight-day experimental protocol substantial changes in grinding kinematics and reductions in the variation of kinematics were seen in the 10 America's Cup level grinder operators.

Predictive factors of grinding performance

Six variables, representing two kinematic parameters and four individual characteristics thought most likely to affect grinding performance, were assessed as predictors of performance.

- COM_x position was a better predictor of grinding performance than pull angle, explaining about 40% of the improvement in performance, in comparison to only 8% explained by the change in pull angle.
- Height, weight, and strength all showed linear relationships with grinding performance of a 2.1-2.9% performance increase per SD increase. There was also an individual variation influence (%/unit/SD) with 0.12-0.26% for change in COM_x position and 0.06-0.15% for pull angle. For example, one SD difference in strength will change the performance effect of a 1-cm change in COM_x position by 0.26%. In theory this means that while an individual of average strength would get a performance increase of 2.9% for a 1 cm COM_x increase, an individual of 1 SD above average strength would get a 3.2% increase in performance from the same change in COM_x position. Unfortunately very few of these results were statistically significant, although the type of trends occurring indicate that this was probably a function of the low subject numbers and trials in this study.
- Brachial index showed only a very small 0.4% performance increase per increase in SD. Combined with individual variation effects of 0.04% and -0.04% for COM_x position and pull angle respectively, and p-values from 0.663 to 0.843 for the three brachial index relationships, it is suggested that there was no real relationship between backward grinding performance and brachial index.

In conclusion, the major predictors of high-load backward grinding performance appear to be maximal strength and COM_x position relative to the grinding pedestal. Additional weaker predictive factors were body weight, standing height, and pull angle. Brachial index does not appear to have any substantial influence on backward grinding performance. Team New Zealand has employed the grinding technique recommended by this study, and the feedback regarding its use has been positive.

Future research

In terms of future research, a major consideration should be the number of subjects involved in the study. While a number of significant results were obtained in this study, in many cases the level of significance appears to have been restricted by low subject numbers. Greater subject numbers would enable more conclusive findings, especially in terms of the technique mechanisms and their relative levels of influence on performance.

The sampling frequencies used in this study for both video (25 Hz) and power output data (40 Hz) were restricted due to the technology available. While sampling frequency was sufficient to enable the research to be completed to an acceptable, any follow-up study should ideally endeavour to employ faster sampling frequencies for both video and power output. In addition, the use of three-dimensional videography and a more comprehensive analysis of the forces involved through force sensors and inverse dynamics may also help the understanding of performance factors.

Another potential area of expansion for subsequent studies may be to approach technique performance of grinding from a motor control perspective. There are likely to be a number of motor coordination implications for performance, in particular with variation between one or two operators grinding at a pedestal, in-phase or out-of-phase movement patterns, and movement direction.

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APPENDICES

Appendix 1: Pilot testing results.

Tables 12-14 show pilot testing results for eleven grinders.

Table 12: High load grinding performance data collected during pilot testing conducted September 2001. Performance is measured as power output/work performed (J) over a five-second period from peak power.

	Test 1							
	Forward				**Backward**			
Subject	**Trial 1**	**Trial 2**	**Mean**	**SD**	**Trial 1**	**Trial 2**	**Mean**	**SD**
1	47909	53999	50954	4306	40720	--	40720	n/a
2	44932	47320	46126	1688	33989	--	33989	n/a
3	48132	51067	49600	2076	40505	--	40505	n/a
4	50129	52177	51153	1448	42970	--	42970	n/a
5	--	--	--	--	--	--	--	--
6	42707	45579	44143	2031	38322	--	38322	n/a
7	50569	49194	49882	972	38633	--	38633	n/a
8	66093	66083	66088	7	55442	--	55442	n/a
9	58543	58545	58544	1	41525	--	41525	n/a
10	46030	52468	49249	4553	37896	--	37896	n/a
11	52121	52555	52338	307	--	--	--	--

Table 13: High load grinding performance data collected during pilot testing conducted December 2001. Performance is measured as power output/work performed (J) over a five-second period from peak power.

	Test 2							
	Forward				**Backward**			
Subject	**Trial 1**	**Trial 2**	**Mean**	**SD**	**Trial 1**	**Trial 2**	**Mean**	**SD**
1	40055	40721	40388	471	28701	31103	29902	1699
2	--	--	--	--	--	--	--	--
3	38431	41532	39981	2193	35609	37015	36312	995
4	40620	42199	41409	1117	36461	34689	35575	1254
5	47775	52486	50130	3331	39056	43432	41244	3094
6	34089	34071	34080	13	29902	29435	29668	331
7	39306	40189	39748	624	33368	35552	34460	1545
8	47226	49034	48130	1278	40108	41110	40609	709
9	40958	42829	41893	1323	26495	30729	28612	2994
10	37575	38952	38264	974	29196	31224	30210	1434
11	37539	40175	38857	1864	33459	33855	33657	280

Table 14: High load grinding performance data collected during pilot testing conducted February 2002. Performance is measured as power output/work performed (J) over a five-second period from peak power.

	Test 3							
	Forward				**Backward**			
Subject	**Trial 1**	**Trial 2**	**Mean**	**SD**	**Trial 1**	**Trial 2**	**Mean**	**SD**
1	39318	39298	39308	15	30328	31264	30796	662
2	33302	33668	33485	259	24340	24804	24572	328
3	41146	41192	41169	32	32649	37929	35289	3734
4	38631	39819	39225	840	27978	33822	30900	4133
5	50646	47046	48846	2545	40870	43319	42094	1732
6	34880	37171	36026	1621	29998	30808	30403	572
7	40455	41060	40757	428	32270	35829	34049	2516
8	47497	48957	48227	1032	35651	38666	37159	2132
9	42812	43958	43385	811	33219	32293	32756	654
10	37678	35993	36836	1192	29401	32712	31056	2341
11	39497	39077	39287	297	33477	31540	32508	1370

Appendix 2: Maximal strength (1RM) prediction

Table 15 gives the conversion formula for determining 1RM from multi-rep performance using the equation:

1RM = 100 × rep weight / (52.2 + 41.9 × EXP [-0.055 × reps])

Table 15: Sample conversion table based on the Mayhew, Barnett, Schutter, and Bemben (1995) formula for determining 1RM from multi-rep performance.

		Number of reps					
		3	**4**	**5**	**6**	**7**	**8**
Rep weight (kg)	**90**	103	105	107	109	112	114
	91	104	106	108	111	113	115
	92	105	107	109	112	114	116
	93	106	108	111	113	115	117
	94	107	110	112	114	116	119
	95	108	111	113	115	118	120
	96	109	112	114	117	119	121
	97	111	113	115	118	120	122
	98	112	114	117	119	121	124
	99	113	115	118	120	123	125
	100	114	117	119	121	124	126
	101	115	118	120	123	125	128
	102	116	119	121	124	126	129
	103	117	120	123	125	128	130
	104	119	121	124	126	129	131
	105	120	122	125	128	130	133
	106	121	124	126	129	131	134
	107	122	125	127	130	133	135
	108	123	126	129	131	134	136
	109	124	127	130	132	135	138
	110	125	128	131	134	136	139
	111	127	129	132	135	138	140
	112	128	130	133	136	139	141

Appendix 3: Subject consent form

Consent to Participation in Research

Title of Project: Enhancing performance in America's Cup grinders

Project Supervisor: Associate Professor Patria Hume

Researcher: Simon Pearson

- I have read and understood the information provided about this research project.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself, or any information that I have provided for this project, at any time prior to completion of data collection, without being disadvantaged in any way. If I withdraw, I understand that all relevant tapes and transcripts, or parts thereof, will be destroyed
- I agree to take part in this research.

Participant signature: ....

Participant name: ______________________________

Date: ______________________________

Project Supervisor Contact Details: Associate Professor Patria Hume

School of Community Health and Sports Studies, Faculty of Health Studies, Auckland University of Technology, Private bag 92006, Auckland. Tel: (09) 9179999 ext. 7306
Email: patria.hume@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on the 27th August 2001. AUTEC Reference number 01/85.

Appendix 4: Subject information package

Subject Information Package

Principal Investigator/ Contact person:

- Associate Professor Patria Hume, Head of Research, Auckland University of Technology, Private Bag 92006, Tel: (09) 9179999 x 7306 Email: patria.hume@aut.ac.nz
- Simon Pearson, MHSc Candidate, Auckland University of Technology, Private Bag 92006, Tel: (09) 9179999 x 7159 Email: simon.pearson@aut.ac.nz

Title:

Enhancing performance in America's Cup grinders.

Introduction:

As a member of the Team New Zealand America's Cup syndicate you are invited to take part in the above mentioned research project. Your participation in this testing is voluntary. You are free to withdraw consent and discontinue participation at anytime without influencing any present and/or future involvement with the Auckland University of Technology.

Your consent to participate in this research will be indicated by your signing and dating the consent form. Signing the consent form indicates that you have freely given your consent to participate, and that there has been no coercion or inducement to participate.

Aim of Study

This project aims to identify the effect of body position and grinding technique on grinding performance on a grinding ergometer.

Participants

All members of the Team New Zealand sailing crew who are involved primarily in grinding during race conditions are invited to participate in this research.

Location

The project will be run at the Team New Zealand base, Auckland.

Time

By participating in the research you will be required to give up 60 minutes on five days over an eight-day period.

Methods

All participants will take part in the experimental condition, acting as their own controls. The initial testing session will provide baseline information on grinding performance. This will be followed by the technique intervention and a post-intervention testing session that will determine the effectiveness of the technique intervention.

Procedures

Part One:

Various measures will be collected including anthropometric measurements (physical dimensions) by ISAK accredited anthropometrists, strength measures from the Team New Zealand trainer, and joint angles during grinding (from video footage). Analysis of this information will help identify determining factors in grinding performance.

Part Two:

Subjects will perform a warm-up on the grinding ergometer consisting of varied intensity bursts (submaximal to maximal) for a period deemed sufficient by the subject.

Four trials will be conducted at each testing session with each trial consisting of an eight second maximal burst in a set gearing (constant resistance), which will remain the same for all testing sessions throughout the study. Eight seconds is considered to provide sufficient information to quantify performance, as well as being comparable with actual race situations.

During each eight-second trial, information on power output will be collected via a computer link to the grinding ergometer. Performance can then be quantified according to power, with variables of particular interest being total power output over the entire trial, and peak power output.

Subjects will be video taped as they grind for analysis of technique changes.

Benefits of the study

This research will provide more information on the biomechanical requirements of grinding, and possible performance improvements in a race situation.

Possible risks of the study

There is possible injury to the subject. This is however an equivalent risk to normal participation in physical training and competition.

Taking part in this research will not cost you.

Results

You will receive a report on your individual results and a copy of the final report will be provided to the Team New Zealand syndicate. The identity of individuals will be made available to the Team New Zealand syndicate, but any information published elsewhere would have subject identities concealed. In the case of any video footage, subject's faces will be obscured/blanked out.

If you have any other questions please feel free to contact Dr Patria Hume or Simon Pearson at any time.

Participant Concerns

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, 917 9999 ext 8044.

APPROVED BY THE AUCKLAND UNIVERSITY OF TECHNOLOGY HUMAN SUBJECTS ETHICS COMMITTEE

on 27/08/2001 for a period of two years. Reference 01/85.

Appendix 5: Test-retest reliability of digitisation

The VEII computer software used for video analysis in this project required manual digitisation of the video footage and was therefore subject to operator error. A test-retest reliability analysis of the manual digitising procedure was conducted in order to determine the possible variation from the researcher digitising over a number of days. One revolution of the grinding ergometer handles from a randomly selected subject was digitised on two separate days. Posterior knee angle was calculated from both sets of data and is displayed in Table 16. Average digitising error was equal to 0.84° with a range from 0.06° to 1.95°.

Table 16: Test-retest digitising data for one grinding cycle.

Frame	**Initial (°)**	**Retest (°)**	**Difference (°)**
1	95.3	96.2	0.87
2	93.8	93.7	0.15
3	93.0	92.1	0.84
4	93.8	94.7	0.87
5	95.0	95.8	0.76
6	98.2	99.9	1.69
7	99.7	99.8	0.10
8	98.2	99.2	0.98
9	96.0	98.0	1.95
10	92.8	94.7	1.90
11	91.6	92.9	1.26
12	92.5	92.6	0.12
13	95.8	94.2	1.60
14	95.8	95.9	0.06
15	96.4	96.8	0.36
16	99.1	98.7	0.34
17	99.8	99.4	0.39
18	99.1	100.0	0.86
Average difference			0.84 (0.06 – 1.95)

Mean ± stdev (range)

Appendix 6: Pre and post-intervention kinematic and performance data for all subjects.

Tables 17-26 show the pre-intervention to post-intervention changes in variables of interest for the eleven grinders.

Table 17: Numerical description of individual subject changes in ankle, knee, and hip angle from pre-intervention to post-intervention testing.

	Ankle angle (°)				**Knee angle (°)**				**Hip angle (°)**			
Subject	**Pre**	**Post**	**Change (%)**	**P-value**	**Pre**	**Post**	**Change (%)**	**P-value**	**Pre**	**Post**	**Change (%)**	**P-value**
1	122	121	-1.6%	0.181	128	119	-7.5%	0.131	105	99	-5.4%	0.208
2	112	105	-6.5%	0.030	108	87	-19.8%	0.045	89	82	-7.9%	0.090
3	119	118	-0.8%	0.802	118	109	-8.1%	0.249	91	92	0.4%	0.713
4	125	116	-7.3%	0.083	123	100	-19.0%	0.022	99	92	-7.8%	0.062
5	130	130	0.1%	0.961	147	126	-14.2%	0.031	107	92	-14.2%	0.084
6	124	125	0.5%	0.751	142	123	-13.4%	0.032	112	102	-9.3%	0.094
7	108	109	0.8%	0.590	96	100	4.1%	0.438	101	98	-3.3%	0.493
8	133	124	-6.9%	0.012	138	134	-2.8%	0.277	88	98	10.9%	0.087
9	121	124	2.4%	0.654	134	117	-12.9%	0.219	103	91	-12.0%	0.091
10	101	113	12.0%	0.047	118	96	-18.6%	0.068	106	94	-11.5%	0.071
11	122	117	-4.3%	0.151	133	116	-13.3%	0.065	112	106	-5.6%	0.252

Table 18: Numerical description of individual subject changes in shoulder, elbow, and trunk angle from pre-intervention to post-intervention testing. Trunk angle is measured relative to vertical.

	Shoulder angle (°)				**Elbow angle (°)**				**Trunk angle (°)**			
Subject	**Pre**	**Post**	**Change (%)**	**P-value**	**Pre**	**Post**	**Change (%)**	**P-value**	**Pre**	**Post**	**Change (%)**	**P-value**
1	45	47	3.3%	0.656	132	137	3.6%	0.147	19	17	-11.0%	0.149
2	56	61	7.7%	0.208	135	135	-0.3%	0.771	26	17	-35.4%	0.088
3	56	55	-1.8%	0.712	141	138	-2.1%	0.350	26	17	-36.2%	0.113
4	49	56	13.6%	0.033	135	141	4.4%	0.185	23	17	-26.7%	0.102
5	42	51	21.7%	0.006	143	140	-2.1%	0.278	35	26	-25.2%	0.011
6	26	39	50.0%	0.097	127	127	0.4%	0.915	25	13	-50.6%	0.003
7	50	53	4.7%	0.450	147	147	-0.2%	0.639	8	10	26.6%	0.379
8	51	48	-6.7%	0.404	133	142	6.8%	0.047	36	28	-23.3%	0.014
9	40	47	16.3%	0.236	124	126	2.0%	0.557	27	20	-25.5%	0.150
10	37	46	24.3%	0.036	136	139	2.1%	0.146	22	12	-48.8%	0.095
11	29	39	35.9%	0.043	119	124	3.4%	0.208	23	15	-37.5%	0.007

Table 19: Numerical description of individual subject changes in ankle-hip angle and ankle-hip distance from pre-intervention to post-intervention testing.

	Ankle-hip angle (°)				**Ankle-hip distance (m)**			
Subject	**Pre**	**Post**	**Change (%)**	**P-value**	**Pre**	**Post**	**Change (%)**	**P-value**
1	60	57	-5.3%	0.156	0.68	0.66	-3.0%	0.275
2	60	54	-11.2%	0.082	0.64	0.54	-16.1%	0.025
3	59	53	-9.4%	0.081	0.69	0.63	-8.8%	0.140
4	61	60	-1.9%	0.425	0.71	0.61	-13.5%	0.026
5	69	55	-19.7%	0.107	0.81	0.74	-8.9%	0.017
6	67	53	-21.1%	0.047	0.74	0.67	-9.5%	0.090
7	62	57	-7.5%	0.096	0.59	0.62	4.6%	0.252
8	55	59	6.8%	0.246	0.84	0.81	-3.7%	0.041
9	65	53	-18.8%	0.021	0.77	0.73	-6.0%	0.281
10	71	56	-20.9%	0.036	0.73	0.64	-12.6%	0.155
11	68	61	-10.8%	0.078	0.67	0.61	-8.3%	0.058

Table 20: Numerical description of individual subject changes in COM$_x$ location (relative to the grinder hub) and range of movement from pre-intervention to post-intervention testing.

	COM$_x$ distance from hub (m)				**COM$_x$ range of movement (m)**			
Subject	**Pre**	**Post**	**Change (%)**	**P-value**	**Pre**	**Post**	**Change**	**P-value**
1	0.34	0.36	3.6%	0.557	0.22	0.20	-0.02	0.055
2	0.38	0.39	4.0%	0.126	0.17	0.17	0.00	0.949
3	0.42	0.43	1.0%	0.854	0.16	0.19	0.03	0.174
4	0.38	0.41	6.6%	0.199	0.19	0.21	0.02	0.317
5	0.40	0.48	20.0%	0.024	0.14	0.18	0.03	0.110
6	0.24	0.31	29.8%	0.010	0.22	0.23	0.01	0.067
7	0.39	0.40	2.4%	0.562	0.17	0.18	0.01	0.401
8	0.55	0.54	-1.8%	0.554	0.16	0.16	-0.01	0.605
9	0.39	0.43	11.5%	0.143	0.22	0.20	-0.02	0.290
10	0.48	0.55	14.3%	0.051	0.12	0.13	0.00	0.943
11	0.25	0.30	18.0%	0.092	0.21	0.19	-0.02	0.175

Table 21: Numerical description of individual subject changes in COM$_y$ location (relative to the grinder hub) and range of movement from pre-intervention to post-intervention testing.

	COM$_y$ distance from hub (m)				**COM$_y$ range of movement (m)**			
Subject	**Pre**	**Post**	**Change**	**P-value**	**Pre**	**Post**	**Change**	**P-value**
1	-0.07	-0.05	0.03	0.086	0.08	0.06	-0.02	0.014
2	-0.05	-0.14	-0.08	0.010	0.10	0.12	0.03	0.309
3	0.00	-0.04	-0.04	0.051	0.06	0.05	-0.01	0.585
4	-0.04	-0.06	-0.02	0.322	0.04	0.04	0.00	0.780
5	0.14	0.09	-0.05	0.051	0.07	0.05	-0.01	0.276
6	0.05	-0.06	-0.11	0.084	0.10	0.10	0.00	0.496
7	-0.05	-0.05	0.01	0.745	0.04	0.04	0.00	0.955
8	0.16	0.18	0.02	0.472	0.07	0.05	-0.02	0.259
9	0.06	0.03	-0.03	0.293	0.09	0.08	-0.01	0.704
10	0.16	0.11	-0.05	0.126	0.05	0.03	-0.02	0.144
11	-0.03	-0.09	-0.06	0.117	0.07	0.05	-0.03	0.161

Table 22: Numerical description of individual subject changes from pre-intervention to post-intervention testing of the magnitude and angle of the vector from the hub of the grinding ergometer to the subjects COM.

	COM vector magnitude (m)				**COM vector angle (°)**			
Subject	**Pre**	**Post**	**Change**	**P-value**	**Pre**	**Post**	**Change**	**P-value**
1	0.43	0.41	-0.02	0.473	-12	-7	4.5	0.022
2	0.44	0.54	0.10	0.025	-8	-19	-11.3	0.007
3	0.43	0.47	0.04	0.147	0	-5	-5.9	0.050
4	0.43	0.47	0.04	0.176	-6	-8	-2.0	0.360
5	0.55	0.57	0.02	0.051	19	11	-8.7	0.047
6	0.32	0.39	0.07	0.140	11	-11	-22.0	0.100
7	0.45	0.45	0.00	0.939	-7	-6	1.0	0.702
8	0.67	0.68	0.00	0.255	16	18	1.9	0.486
9	0.46	0.46	0.00	0.647	9	4	-5.1	0.297
10	0.62	0.64	0.02	0.153	18	11	-6.9	0.125
11	0.30	0.41	0.11	0.142	-7	-16	-9.6	0.165

Table 23: Numerical descriptions of individual subject changes in hip joint location and displacement from pre-intervention to post-intervention testing.

	Hip$_x$ distance from hub (m)				**Hip$_y$ distance from hub (m)**			
Subject	**Pre**	**Post**	**Change (%)**	**P-value**	**Pre**	**Post**	**Change**	**P-value**
1	0.51	0.53	4.0%	0.396	-0.17	-0.17	-0.01	0.712
2	0.59	0.58	-1.7%	0.500	-0.15	-0.26	-0.12	0.024
3	0.59	0.56	-4.3%	0.492	-0.13	-0.20	-0.08	0.042
4	0.57	0.58	2.7%	0.205	-0.13	-0.18	-0.06	0.110
5	0.53	0.60	13.2%	0.090	0.02	-0.11	-0.13	0.025
6	0.41	0.48	15.9%	0.055	-0.01	-0.17	-0.16	0.079
7	0.53	0.55	4.8%	0.316	-0.19	-0.18	0.01	0.705
8	0.64	0.61	-5.5%	0.305	-0.02	-0.03	-0.01	0.712
9	0.53	0.57	7.5%	0.259	-0.06	-0.14	-0.09	0.146
10	0.52	0.56	7.8%	0.030	-0.08	-0.19	-0.11	0.114
11	0.45	0.48	6.7%	0.205	-0.09	-0.16	-0.08	0.067

*The change in hip$_y$ is expressed as an absolute because a percentage change was considered inappropriate due to some of the measures changing from positive to negative values.

Table 24: Numerical description of individual subject changes in shoulder$_x$ location (relative to the grinder hub) and range of movement from pre-intervention to post-intervention testing.

	Shoulder$_x$ distance from hub (m)				**Shoulder$_x$ range of movement (m)**			
Subject	**Pre**	**Post**	**Change (%)**	**P-value**	**Pre**	**Post**	**Change**	**P-value**
1	0.35	0.38	7.1%	0.344	*0.30*	*0.31*	0.01	0.494
2	0.38	0.44	17.3%	0.049	*0.24*	*0.26*	0.02	0.682
3	0.38	0.44	14.5%	0.069	*0.26*	*0.28*	0.02	0.403
4	0.39	0.44	12.8%	0.072	*0.24*	*0.27*	0.03	0.228
5	0.24	0.38	56.3%	0.019	*0.21*	*0.30*	0.09	0.049
6	0.21	0.37	76.2%	0.040	*0.33*	*0.34*	0.01	0.553
7	0.47	0.47	1.1%	0.500	*0.28*	*0.29*	0.01	0.535
8	0.35	0.38	7.1%	0.430	*0.24*	*0.25*	0.01	0.747
9	0.32	0.41	28.6%	0.230	*0.34*	*0.31*	-0.03	0.081
10	0.33	0.46	40.0%	0.110	*0.23*	*0.26*	0.02	0.365
11	0.27	0.37	37.7%	0.005	*0.26*	*0.24*	-0.02	0.467

Table 25: Numerical description of individual subject changes in shoulder$_y$ location (relative to the grinder hub) and range of movement from pre-intervention to post-intervention testing.

	Shoulder$_y$ distance from hub (m)				**Shoulder$_y$ range of movement (m)**			
Subject	**Pre**	**Post**	**Change**	**P-value**	**Pre**	**Post**	**Change**	**P-value**
1	0.27	0.30	0.03	0.126	0.15	0.12	-0.03	0.133
2	0.29	0.20	-0.10	0.033	0.20	0.25	0.05	0.029
3	0.30	0.24	-0.06	0.105	0.16	0.13	-0.03	0.208
4	0.30	0.28	-0.02	0.396	0.11	0.09	-0.03	0.249
5	0.43	0.36	-0.07	0.049	0.17	0.16	-0.01	0.812
6	0.40	0.29	-0.11	0.114	0.18	0.16	-0.02	0.279
7	0.28	0.28	0.00	1.000	0.11	0.09	-0.02	0.639
8	0.39	0.41	0.03	0.492	0.23	0.18	-0.05	0.234
9	0.36	0.32	-0.04	0.328	0.21	0.22	0.01	0.825
10	0.39	0.31	-0.08	0.030	0.13	0.10	-0.03	0.198
11	0.35	0.28	-0.06	0.084	0.15	0.10	-0.06	0.084

Table 26: Numerical description of individual subject changes from pre-intervention to post-intervention testing of the magnitude and angle of the vector from the hub of the grinding ergometer to the subjects average shoulder position, and grinding output (performance).

	Shoulder vector magnitude (m)				**Shoulder vector angle (°)**				**Grinding Output (J)**			
Subject	**Pre**	**Post**	**Change**	**P-value**	**Pre**	**Post**	**Change**	**P-value**	**Pre**	**Post**	**Change (%)**	**P-value**
1	0.63	0.66	0.03	0.089	38	38	0.5	0.780	45917	48571	5.8%	0.135
2	0.66	0.62	-0.03	0.028	38	24	-13.8	0.004	37677	37210	-1.2%	0.610
3	0.67	0.66	-0.01	0.126	38	29	-9.4	0.104	51210	52591	2.7%	0.348
4	0.67	0.68	0.02	0.133	37	32	-5.1	0.186	52095	56166	7.8%	0.217
5	0.69	0.71	0.01	0.129	61	44	-16.7	0.035	55613	58285	4.8%	0.242
6	0.67	0.65	-0.01	0.471	62	38	-24.2	0.061	42819	44384	3.7%	0.206
7	0.70	0.70	0.00	0.736	31	30	-0.3	0.901	57501	53443	-7.1%	0.127
8	0.71	0.74	0.03	0.159	48	48	-0.2	0.977	58280	60120	3.2%	0.375
9	0.67	0.69	0.02	0.256	48	38	-10.5	0.266	43268	47921	10.8%	0.114
10	0.70	0.72	0.02	0.132	50	34	-15.9	0.080	47138	54219	15.0%	0.103
11	0.64	0.64	0.00	0.906	52	37	-15.0	0.024	44764	42995	-4.0%	0.062

Appendix 7: Programming details of the Proc-mixed group analyses run using the SAS analysis programme.

```
***analyses ex anthro test sas.doc;
libname  ss  "D:\Will's  Documents\Projects\Patria  Hume\Simon
Pearson grinders";
filename    inkine    "D:\Will's    Documents\Projects\Patria
Hume\Simon Pearson grinders\kine data.txt";
filename  inchar  "D:\Will's  Documents\Projects\Patria  Hume\Simon
Pearson grinders\characteristics.txt";
options nodate;

data charac;
infile inchar missover firstobs=2 delimiter='09'x;
input Athlete Age Height UppLegLngth LowLegLngth TotLegLngth
SitHeight ArmLnght BrachIndex BenchPull Weight;

*proc print;
run;

data mean;
infile inkine missover firstobs=3 delimiter='09'x;
mmm="Mean";
length trial $ 7;
input athlete trial $ work AnkleHipDist d1 d2 AnkleAngle d1 d2
AnkleHipAngle d1 d2 ElbowAngle d1 d2 HipAngle d1 d2 KneeAngle
d1 d2 ShouldAngle d1 d2 TrunkAngle d1 d2 COM_x d1 d2 COM_y d1
d2  Hip_x  d1  d2  Hip_y  d1  d2  Should_x  d1  d2  Should_y  d1  d2
PullAngle;
time=0+substr(trial,1,1);
if athlete=7 then delete;
drop d1 d2;
COM_x=100*COM_x;

*proc print;
run;


data max;
infile inkine missover firstobs=3 delimiter='09'x;
mmm="Max";
length trial $ 7;
input athlete trial $ work d1 AnkleHipDist d1 d2 AnkleAngle d1
d2  AnkleHipAngle  d1  d2  ElbowAngle  d1  d2  HipAngle  d1  d2
KneeAngle d1 d2 ShouldAngle d1 d2 TrunkAngle d1 d2 COM_x d1 d2
COM_y  d1  d2  Hip_x  d1  d2  Hip_y  d1  d2  Should_x  d1  d2  Should_y
d1;
time=0+substr(trial,1,1);
if athlete=7 then delete;
drop d1 d2;

data min;
infile inkine missover firstobs=3 delimiter='09'x;
mmm="Min";
```

```
length trial $ 7;
input athlete trial $ work d1 d2 AnkleHipDist d1 d2 AnkleAngle
d1 d2 AnkleHipAngle d1 d2 ElbowAngle d1 d2 HipAngle d1 d2
KneeAngle d1 d2 ShouldAngle d1 d2 TrunkAngle d1 d2 COM_x d1 d2
COM_y d1 d2 Hip_x d1 d2 Hip_y d1 d2 Should_x d1 d2 Should_y;
time=0+substr(trial,1,1);
if athlete=7 then delete;
drop d1 d2;

title "Means and SDs for potential predictors of indiv
responses";
proc means n mean std min max maxdec=1 data=charac;
var height weight BenchPull BrachIndex;
run;

*rely and mechanisms analysis;
data datlog;
merge charac mean;
by athlete;
work=100*log(work/1000); *work in kJ;
*COM_x=100*log(COM_x); *not log transforming mech variables;
if trial="1.pre1" then delete;
if trial="2.post1" then delete;
if time=2 then xvar=1; *dummy var for indiv responses;
  else xvar=0;

proc sort data=datlog;
by time;

%macro analyze;

title1 "Simple rely analysis for work (as %), by time";
data cov est pred lsm;

ods listing close;
proc mixed covtest cl data=datlog;
class athlete trial;
model work=trial/outp=pred; *standard rely model;
random athlete;
estimate "Trial 2-1" trial –1 1 0/cl;
estimate "Trial 3-2" trial 0 –1 1/cl;
ods output covparms=cov;
ods output estimates=est;
by time;
run;
ods listing;

options linesize=80 pagesize=40;
proc plot data=pred;
plot resid*pred;
title2 "Residuals";
title3 "for second and third trials on each day";
by time;
run;

data est1;
```

```
set est(rename=(Probt=P_value));
Estimate=100*exp(Estimate/100)-100;
Lower=100*exp(Lower/100)-100;
Upper=100*exp(Upper/100)-100;
CLpm=(upper-lower)/2;
if Label=" " then estimate=.;

options linesize=80 pagesize=65;
proc print data=est1 noobs;
var time Label Estimate P_value CLpm Lower Upper;
format _numeric_ 7.1 time 4.0 P_value 7.4;
title2 "Fixed effects (here, the learning effects)";
run;

data cov1;
set cov;
CV=100*exp(sqrt(estimate)/100)-100;
CVlow=100*exp(sqrt(Lower)/100)-100;
CVupp=100*exp(sqrt(Upper)/100)-100;
rename estimate=Variance;

proc print data=cov1 noobs;
var time covparm CV CVlow CVupp Variance Lower Upper;
format _numeric_ 6.1;
title2 "Back-transformed random effects, expressed as CV (%)";
run;

title1 "Simple rely analysis for &mechvar (not as %), by time";
data cov est pred lsm;

ods listing close;
proc mixed covtest cl data=datlog;
class athlete trial;
model &mechvar=trial/outp=pred; *standard rely model;
random athlete;
estimate "Trial 2-1" trial –1 1 0/cl;
estimate "Trial 3-2" trial 0 –1 1/cl;
ods output covparms=cov;
ods output estimates=est;
by time;
run;
ods listing;

options linesize=80 pagesize=40;
proc plot data=pred;
plot resid*pred;
title2 "Residuals";
title3 "for second and third trials on each day";
by time;
run;

data est1;
set est(rename=(Probt=P_value));
CLpm=(upper-lower)/2;
if Label=" " then estimate=.;
```

```
options linesize=80 pagesize=65;
proc print data=est1 noobs;
var time Label Estimate P_value CLpm Lower Upper;
format _numeric_ 7.1 time 4.0 P_value 7.4;
title2 "Fixed effects (here, the learning effects)";
run;

data cov1;
set cov;
SD=sqrt(estimate);
SDlow=sqrt(Lower);
SDupp=sqrt(Upper);
rename estimate=Variance;

proc print data=cov1 noobs;
var time covparm SD SDlow SDupp Variance Lower Upper;
format _numeric_ 6.1;
title2 "Back-transformed random effects, expressed as raw SD";
run;

*now the mechanisms etc analysis;
title1 "Effect of time on work";
data cov est pred lsm;

ods listing close;
proc mixed covtest cl data=datlog;
class athlete time;
model work=time/outp=pred;
random athlete athlete*xvar;
lsmeans time;
ods output lsmeans=lsm;
*random athlete athlete*time; *standard random effects model;
estimate "post-pre" time –1 1/cl;
ods output covparms=cov;
ods output estimates=est;
run;
ods listing;

options linesize=80 pagesize=40;
proc plot data=pred;
plot resid*pred=time;
title2 "Residuals";
title3 "for second and third trials on each day";
run;

data lsm1;
set lsm;
estimate=exp(estimate/100);
drop stderr--probt;

proc print data=lsm1 noobs;
format estimate 5.1;
title2 "Back-transformed least-squares means for work";
run;
```

```
data est1;
set est(rename=(Probt=P_value));
Estimate=100*exp(Estimate/100)-100;
Lower=100*exp(Lower/100)-100;
Upper=100*exp(Upper/100)-100;
CLpm=(upper-lower)/2;
if Label=" " then estimate=.;

options linesize=80 pagesize=65;
proc print data=est1 noobs;
var Label Estimate P_value CLpm Lower Upper;
format _numeric_ 7.2 P_value 7.4;
title2 "Fixed effects (%)";
run;

data cov1;
set cov;
CV=100*exp(sqrt(estimate)/100)-100;
CVlow=100*exp(sqrt(Lower)/100)-100;
CVupp=100*exp(sqrt(Upper)/100)-100;
rename estimate=Variance;

proc print data=cov1 noobs;
var covparm CV CVlow CVupp Variance Lower Upper ProbZ;
format _numeric_ 6.1 ProbZ 6.4;
title2 "Back-transformed random effects, expressed as CV (%)";
run;

title1 "Effect of time on &mechvar";
data cov est pred lsm;

ods listing close;
proc mixed covtest cl data=datlog;
class athlete time;
model &mechvar=time/outp=pred;
random athlete athlete*xvar;
lsmeans time;
ods output lsmeans=lsm;
*random athlete athlete*time; *standard random effects model;
estimate "post-pre" time –1 1/cl;
ods output covparms=cov;
ods output estimates=est;
run;
ods listing;

options linesize=80 pagesize=40;
proc plot data=pred;
plot resid*pred=time;
title2 "Residuals";
title3 "for second and third trials on each day";
run;

data lsm1;
set lsm;
estimate=exp(estimate/100);
drop stderr--probt;
```

```
proc print data=lsm1 noobs;
format estimate 6.3;
title2 "Back-transformed least-squares means for &mechvar";
run;

data est1;
set est(rename=(Probt=P_value));
Estimate=100*exp(Estimate/100)-100;
Lower=100*exp(Lower/100)-100;
Upper=100*exp(Upper/100)-100;
CLpm=(upper-lower)/2;
if Label=" " then estimate=.;

options linesize=80 pagesize=65;
proc print data=est1 noobs;
var Label Estimate P_value CLpm Lower Upper;
format _numeric_ 7.1 P_value 7.4;
title2 "Fixed effects (%)";
run;

data cov1;
set cov;
CV=100*exp(sqrt(estimate)/100)-100;
CVlow=100*exp(sqrt(Lower)/100)-100;
CVupp=100*exp(sqrt(Upper)/100)-100;
rename estimate=Variance;

proc print data=cov1 noobs;
var covparm CV CVlow CVupp Variance Lower Upper ProbZ;
format _numeric_ 6.1 ProbZ 6.4;
title2 "Back-transformed random effects, expressed as CV (%)";
run;

title1 "Effect of &mechvar on work";
data cov est pred lsm;

ods listing close;
proc mixed covtest cl data=datlog;
class athlete;
model work=&mechvar/outp=pred;
random athlete athlete*xvar athlete*&mechvar;
*random athlete athlete*time; *standard random effects model;
estimate "&mechvar effect %/unit" &mechvar 1/cl;
ods output covparms=cov;
ods output estimates=est;
run;
ods listing;

options linesize=80 pagesize=40;
proc plot data=pred;
plot resid*pred=time;
title2 "Residuals";
title3 "for second and third trials on each day";
run;
```

```
data est1;
set est(rename=(Probt=P_value));
Estimate=100*exp(Estimate/100)-100;
Lower=100*exp(Lower/100)-100;
Upper=100*exp(Upper/100)-100;
CLpm=(upper-lower)/2;
if Label=" " then estimate=.;

options linesize=80 pagesize=65;
proc print data=est1 noobs;
var Label Estimate P_value CLpm Lower Upper;
format _numeric_ 7.2 P_value 7.4;
title2 "Fixed effects (%)";
run;

data cov1;
set cov;
CV=100*exp(sqrt(estimate)/100)-100;
CVlow=100*exp(sqrt(Lower)/100)-100;
CVupp=100*exp(sqrt(Upper)/100)-100;
rename estimate=Variance;

proc print data=cov1 noobs;
var covparm CV CVlow CVupp Variance Lower Upper ProbZ;
format _numeric_ 6.1 ProbZ 6.4;
title2 "Back-transformed random effects, expressed as CV (%)";
run;

title1 "Effect of time and &mechvar on work";
data cov est pred lsm;

ods listing close;
proc mixed covtest cl data=datlog;
class athlete time;
model work=time &mechvar/outp=pred;
random athlete athlete*xvar athlete*&mechvar;
lsmeans time;
ods output lsmeans=lsm;
*random athlete athlete*time; *standard random effects model;
estimate "time post-pre" time –1 1/cl;
estimate "&mechvar effect %/unit" &mechvar 1/cl;
ods output covparms=cov;
ods output estimates=est;
run;
ods listing;

options linesize=80 pagesize=40;
proc plot data=pred;
plot resid*pred=time;
title2 "Residuals";
title3 "for second and third trials on each day";
run;

data lsm1;
set lsm;
estimate=exp(estimate/100);
```

```
drop stderr--probt;

proc print data=lsm1 noobs;
format estimate 5.1;
title2 "Back-transformed least-squares means for work,
controlled for &mechvar";
run;

data est1;
set est(rename=(Probt=P_value));
Estimate=100*exp(Estimate/100)-100;
Lower=100*exp(Lower/100)-100;
Upper=100*exp(Upper/100)-100;
CLpm=(upper-lower)/2;
if Label=" " then estimate=.;

options linesize=80 pagesize=65;
proc print data=est1 noobs;
var Label Estimate P_value CLpm Lower Upper;
format _numeric_ 7.2 P_value 7.4;
title2 "Fixed effects (%)";
run;

data cov1;
set cov;
CV=100*exp(sqrt(estimate)/100)-100;
CVlow=100*exp(sqrt(Lower)/100)-100;
CVupp=100*exp(sqrt(Upper)/100)-100;
rename estimate=Variance;

proc print data=cov1 noobs;
var covparm CV CVlow CVupp Variance Lower Upper ProbZ;
format _numeric_ 6.1 ProbZ 6.4;
title2 "Back-transformed random effects, expressed as CV (%)";
run;

*now the indiv responses analysis;
title1 "Effect of time and &indiv on work";
proc means n mean std min max maxdec=1 data=charac;
var &indiv;
title2 "Univariate statistics for &indiv";
run;

data cov est pred lsm;

ods listing close;
proc mixed covtest cl data=datlog;
class athlete time;
model work=time time*&indiv/outp=pred;
random athlete athlete*xvar;
lsmeans time;
ods output lsmeans=lsm;
*random athlete athlete*time; *standard random effects model;
estimate "time post-pre" time –1 1 time*&indiv –&MeanIndiv
&MeanIndiv/cl;
estimate "&indiv indiv responses %/unit" time*&indiv –1 1/cl;
```

```
ods output covparms=cov;
ods output estimates=est;
run;
ods listing;

options linesize=80 pagesize=40;
proc plot data=pred;
plot resid*pred=time;
title2 "Residuals";
title3 "for second and third trials on each day";
run;

data lsm1;
set lsm;
estimate=exp(estimate/100);
drop stderr--probt;

proc print data=lsm1 noobs;
format estimate 5.1;
title2 "Back-transformed least-squares means for work,
controlled for &indiv";
run;

data est1;
set est(rename=(Probt=P_value));
Estimate=100*exp(Estimate/100)-100;
Lower=100*exp(Lower/100)-100;
Upper=100*exp(Upper/100)-100;
CLpm=(upper-lower)/2;
if Label=" " then estimate=.;

options linesize=80 pagesize=65;
proc print data=est1 noobs;
var Label Estimate P_value CLpm Lower Upper;
format _numeric_ 7.2 P_value 7.4;
title2 "Fixed effects (%)";
run;

data cov1;
set cov;
CV=100*exp(sqrt(estimate)/100)-100;
CVlow=100*exp(sqrt(Lower)/100)-100;
CVupp=100*exp(sqrt(Upper)/100)-100;
rename estimate=Variance;

proc print data=cov1 noobs;
var covparm CV CVlow CVupp Variance Lower Upper ProbZ;
format _numeric_ 6.1 ProbZ 6.4;
title2 "Back-transformed random effects, expressed as CV (%)";
run;

*finally how much does &indiv account for any indiv
differences in the mechanism;
title1 "Effect of subj charac &indiv on effect of mech var
&mechvar";
title4 "Analysis is suspect; wait and see what happens";
```

```
data cov est pred lsm;

ods listing close;
proc mixed covtest cl data=datlog;
class athlete time;
model work=time &mechvar &indiv*&mechvar/outp=pred;
random athlete athlete*xvar athlete*&mechvar;
*random athlete athlete*&mechvar;
lsmeans time;
ods output lsmeans=lsm;
*random athlete athlete*time; *standard random effects model;
estimate "time post-pre" time –1 1/cl;
estimate "&mechvar effect %/unit" &mechvar 1 &indiv*&mechvar
&MeanIndiv/cl;
estimate "&indiv*&mechvar %/unit/unit" &indiv*&mechvar 1/cl;
estimate "&indiv*&mechvar %/unit/SDindiv" &indiv*&mechvar
&SDindiv/cl;
ods output covparms=cov;
ods output estimates=est;
run;
ods listing;

options linesize=80 pagesize=40;
proc plot data=pred;
plot resid*pred=time;
title2 "Residuals";
title3 "for second and third trials on each day";
run;

data lsm1;
set lsm;
estimate=exp(estimate/100);
drop stderr--probt;

proc print data=lsm1 noobs;
format estimate 5.1;
title2 "Back-transformed least-squares means for work,
controlled for &indiv";
run;

data est1;
set est(rename=(Probt=P_value));
Estimate=100*exp(Estimate/100)-100;
Lower=100*exp(Lower/100)-100;
Upper=100*exp(Upper/100)-100;
CLpm=(upper-lower)/2;
if Label=" " then estimate=.;

options linesize=80 pagesize=65;
proc print data=est1 noobs;
var Label Estimate P_value CLpm Lower Upper;
format _numeric_ 7.2 P_value 7.4;
title2 "Fixed effects (%)";
run;

data cov1;
```

```
set cov;
CV=100*exp(sqrt(estimate)/100)-100;
CVlow=100*exp(sqrt(Lower)/100)-100;
CVupp=100*exp(sqrt(Upper)/100)-100;
rename estimate=Variance;

proc print data=cov1 noobs;
var covparm CV CVlow CVupp Variance Lower Upper ProbZ;
format _numeric_ 6.1 ProbZ 6.4;
title2 "Back-transformed random effects, expressed as CV (%)";
run;


%mend;

%let mechvar=com_x;
%let indiv=height;
%let MeanIndiv=187.5;
%let SDindiv=7.2;
%analyze;


%let mechvar=PullAngle;
%analyze;


%let mechvar=com_x;
%let indiv=weight;
%let MeanIndiv=104.7;
%let SDindiv=8.9;
%analyze;

%let mechvar=PullAngle;
%analyze;


%let mechvar=com_x;
%let indiv=BenchPull;
%let MeanIndiv=114.8;
%let SDindiv=10.6;
%analyze;

%let mechvar=PullAngle;
%analyze;


%let mechvar=com_x;
%let indiv=BrachIndex;
%let MeanIndiv=80.1;
%let SDindiv=2.5;
%analyze;

%let mechvar=PullAngle;
%analyze;
```

Appendix 8: Results of Proc-mixed group analyses from the SAS analysis programme.

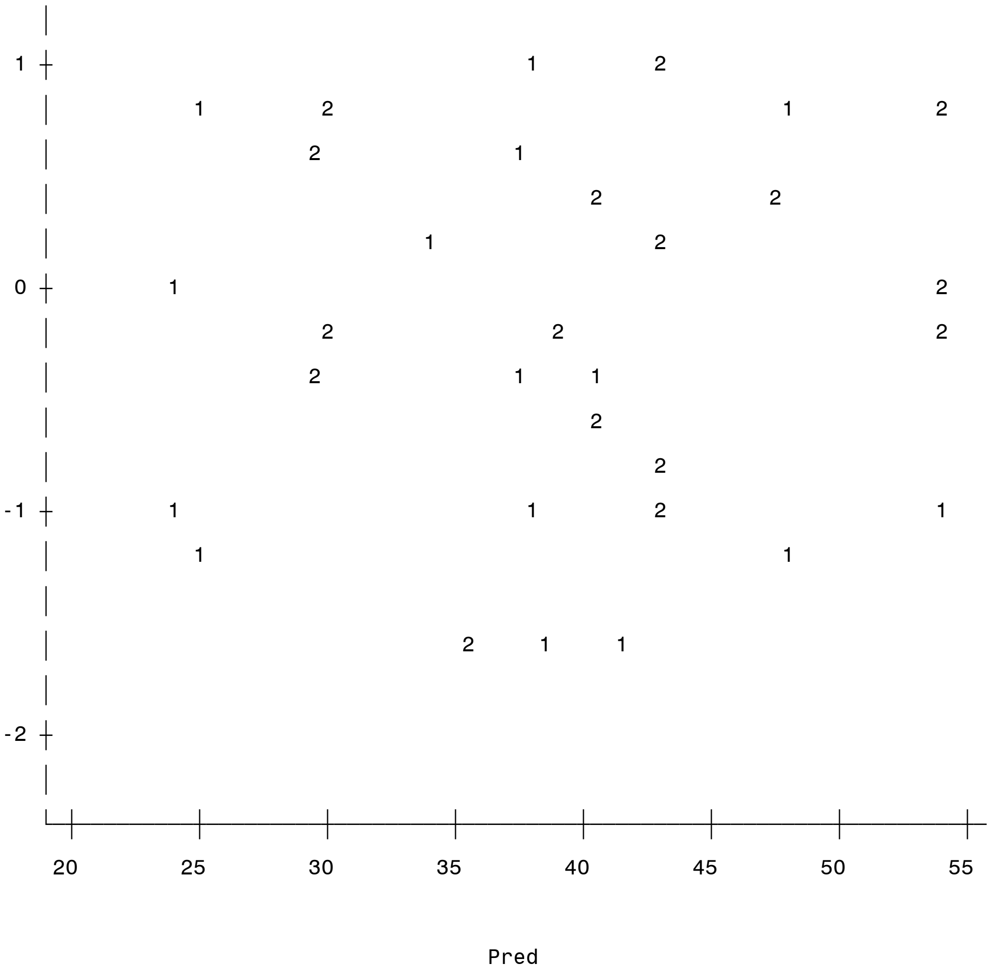
```
                 Simple rely analysis for work (as %), by time               276
                   Fixed effects (here, the learning effects)

  time      Label      Estimate    P_value       CLpm      Lower      Upper


     1    Trial 2-1        0.3      0.7764        2.6       -2.2        3.0
     1    Trial 3-2         .         .            .          .          .
     2    Trial 2-1        0.7      0.4243        2.0       -1.3        2.8
     2    Trial 3-2         .         .            .          .          .



                 Simple rely analysis for work (as %), by time               277
              Back-transformed random effects, expressed as CV (%)

 time     CovParm          CV      CVlow      CVupp    Variance      Lower      Upper


  1.0     Athlete        14.1        9.4       27.6       172.9       80.9      593.9
  1.0     Residual        2.6        1.8        4.8         6.5        3.1       21.8
  2.0     Athlete        16.3       10.9       32.0       227.8      107.2      769.4
  2.0     Residual        2.0        1.4        3.7         3.9        1.8       13.0




               Simple rely analysis for com_x (not as %), by time            280
                   Fixed effects (here, the learning effects)

  time      Label      Estimate    P_value       CLpm      Lower      Upper


     1    Trial 2-1       -1.0      0.1582        1.5       -2.5        0.5
     1    Trial 3-2         .         .            .          .          .
     2    Trial 2-1       -0.7      0.1108        0.9       -1.6        0.2
     2    Trial 3-2         .         .            .          .          .


               Simple rely analysis for com_x (not as %), by time            281
              Back-transformed random effects, expressed as raw SD

 time     CovParm          SD      SDlow      SDupp    Variance      Lower      Upper


  1.0     Athlete         9.3        6.4       17.1        86.5       40.6      293.9
```

1.0	Residual	1.5	1.0	2.7	2.1	1.0	7.0
2.0	Athlete	8.6	5.9	15.7	73.7	34.7	247.6
2.0	Residual	0.9	0.6	1.6	0.8	0.4	2.6

```
                             Effect of time on work                          282
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |                                                       2
      |
      |                                      2
      |                                                   1              1
      |                                                           1
    2 +     1                                          1
      |                                 1
      |                            2           2
      |                            1
      |                         1                                   2    2
      |                       1    1         1                                2
    0 +                         2                          2        2
      |    2                                               2                  2
      |    2                  1                                          2
      |
      |                         2  2           2       1
      |     1                   1                                        1
   -2 +                                 1    1                2   1
      |
      |
      |                                                   1
      |
      |
   -4 +
      |
      +-+-------------+-------------+-------------+-------------+-------------+-
       360           370           380           390           400           410

                                         Pred
NOTE: 1 obs hidden.
```

```
                             Effect of time on work                          283
```

```
                 Back-transformed least-squares means for work

                           Effect    time    Estimate

                            time      1        47.5
                            time      2        49.7


                             Effect of time on work                          284
                               Fixed effects (%)

         Label      Estimate    P_value       CLpm      Lower      Upper

        post-pre       4.73      0.0115       3.63       1.16       8.42



                             Effect of time on work                          285
              Back-transformed random effects, expressed as CV (%)

 CovParm            CV    CVlow    CVupp   Variance    Lower    Upper    ProbZ

 Athlete          14.2      9.5     27.8     176.5      82.9    600.1   0.0181
 xvar*Athlete      4.9      3.1     11.0      22.7       9.5    108.8   0.0407
 Residual          2.2      1.7      3.2       4.8       2.8     10.0   0.0007


                            Effect of time on com_x                          286
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid │
    3 ┼
      │
      │
      │                                            1
      │
    2 ┼                                                                     1
      │
      │
      │                                2     1
```



```
NOTE: 5 obs hidden.


                          Effect of time on com_x                          287
               Back-transformed least-squares means for com_x


                         Effect    time    Estimate


                          time      1        1.464
                          time      2        1.517



                          Effect of time on com_x                          288
                             Fixed effects (%)


       Label      Estimate     P_value       CLpm      Lower      Upper


      post-pre        3.6      0.0012        2.0        1.6        5.7
```

```
                            Effect of time on com_x                          289
              Back-transformed random effects, expressed as CV (%)

 CovParm            CV    CVlow    CVupp   Variance    Lower    Upper    ProbZ


 Athlete           9.6      6.5     18.4      84.7      39.8    286.6   0.0178
 xvar*Athlete      2.7      1.7      6.2       7.2       2.9     36.3   0.0445
 Residual          1.3      1.0      1.9       1.7       1.0      3.6   0.0009



                            Effect of com_x on work                          290
                                   Residuals
                    for second and third trials on each day


                 Plot of Resid*Pred.  Symbol is value of time.


Resid |
      |
    4 +                                                      2
      |
      |
      |                                       2                         1
      |                                                           1
      |                                       2
    2 +
      |                           12                       1
      |      1                          1                          2
      |
      |                                                   2              2
      |                       12                                            22
    0 +                      1                           1
      |    2                        1                1     2        2
      |                           1           1                          2
      |                        1            2
      |                                     1
      |     1                   2                                 1
   -2 +                             2            2
      |                                 1                     2
      |                                                  1
      |
      |                                                                    1
      |
   -4 +
```

```
      |
      +-+-------------+-------------+-------------+-------------+-------------+-
       360           370           380           390           400           410

                                        Pred

NOTE: 1 obs hidden.


                            Effect of com_x on work                          291
                               Fixed effects (%)

         Label           Estimate    P_value       CLpm      Lower      Upper


  com_x effect %/unit       0.72      0.0123       0.52       0.20       1.24


                            Effect of com_x on work                          292
              Back-transformed random effects, expressed as CV (%)

 CovParm              CV     CVlow     CVupp   Variance    Lower     Upper    ProbZ


 Athlete            11.6       7.8      22.8      120.9     56.2     422.1   0.0197
 xvar*Athlete        4.9       3.1      11.0       22.9      9.6     109.0   0.0404
 COM_x*Athlete       0.0         .         .        0.0        .         .      .
 Residual            2.3       1.7       3.4        5.1      3.0      11.0   0.0010


                        Effect of time and com_x on work                     293
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |                                                       2
      |
      |                                                                 1
      |                                                           1
      |                                       2
    2 +                                                   1
```

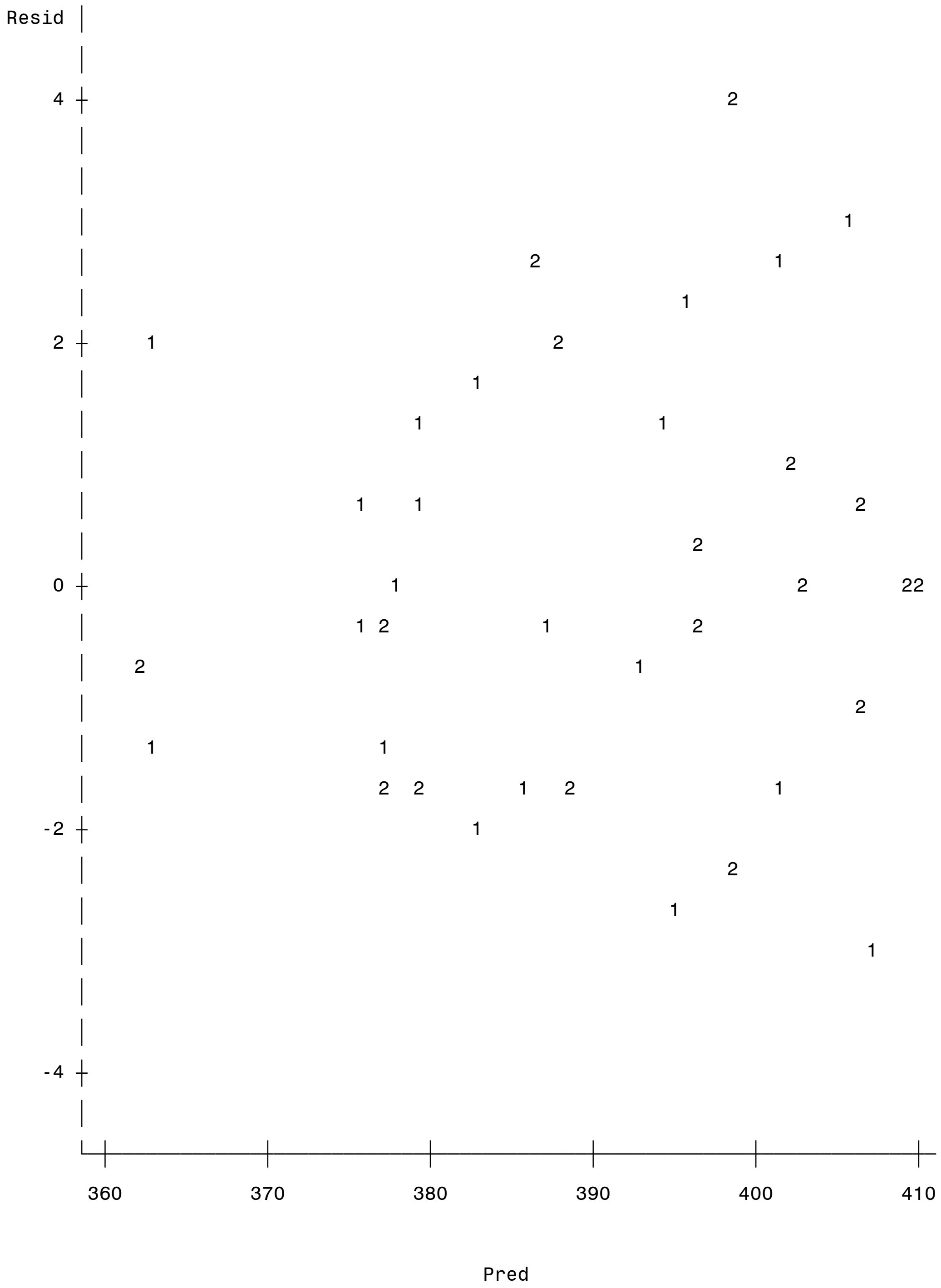
```
      |     1                     1     1
      |                            2
      |                                                            2
      |                                                 1                2
      |                       1                           2
    0 +                      1 2    1                                        22
      |    2                     1           1       1     2        2
      |    2
      |                        1                                         2
      |     1                               2
      |                         2           1                     1
   -2 +                             2   1       2
      |                                                       2
      |                                                  1
      |                                                                   1
      |
      |
   -4 +
      |
      └-+-------------+-------------+-------------+-------------+-------------+-
       360           370           380           390           400           410

                                         Pred

NOTE: 1 obs hidden.

                        Effect of time and com_x on work                     294
      Back-transformed least-squares means for work, controlled for com_x

                           Effect    time    Estimate

                            time      1        47.9
                            time      2        49.3


                        Effect of time and com_x on work                     295
                               Fixed effects (%)

         Label           Estimate    P_value       CLpm      Lower      Upper

  time post-pre             2.75      0.1659       4.14      -1.30       6.98
  com_x effect %/unit       0.54      0.0655       0.58      -0.04       1.12
```

```
                        Effect of time and com_x on work                     296

              Back-transformed random effects, expressed as CV (%)


CovParm              CV     CVlow     CVupp    Variance     Lower     Upper     ProbZ


Athlete            12.0       8.0      24.1       129.0      59.2     466.2    0.0218

xvar*Athlete        4.6       3.0      10.7        20.6       8.5     104.2    0.0446

COM_x*Athlete       0.0        .         .          0.0        .         .      .

Residual            2.2       1.7       3.3         4.9       2.9      10.4    0.0009
```

```
                       Effect of time and weight on work                      297
                        Univariate statistics for weight

                              The MEANS Procedure
                           Analysis Variable : Weight

        N            Mean         Std Dev         Minimum         Maximum
       ------------------------------------------------------------------
       10           104.7             8.9            95.4           120.1
       ------------------------------------------------------------------
```

```
                       Effect of time and weight on work                      298
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |
      |                                               2
      |                                2                      1
      |                                          1      1
      |
    2 +   1                                    1
      |                                  2
      |                       2    1
      |                       1                           2
      |                                                        2
      |                   1 1 1       1                   2
    0 +                    2                       2
      |   2                                        2               2
      |                   1
      |                                  2                     2   2
      |                    2  2                1              1
      |   1                            2                 1
   -2 +                     1      1  1
      |                                               2
      |
      |
      |                                          1
```

```
        |
     -4 +
        |
        |
        └┼───────────┼───────────┼───────────┼───────────┼───────────┼───────────┼
        360         370         380         390         400         410         420

                                           Pred
NOTE: 1 obs hidden.


                      Effect of time and weight on work                     299
      Back-transformed least-squares means for work, controlled for weight

                          Effect    time    Estimate

                           time      1        47.5
                           time      2        49.7


                      Effect of time and weight on work                     300
                              Fixed effects (%)

Label                           Estimate   P_value      CLpm     Lower     Upper

time post-pre                      4.74     0.0043      3.14      1.65      7.93
weight indiv responses %/unit      0.33     0.0682      0.35     -0.03      0.68


                      Effect of time and weight on work                     301
              Back-transformed random effects, expressed as CV (%)

 CovParm           CV     CVlow     CVupp   Variance    Lower     Upper    ProbZ

 Athlete         12.1       8.0      24.9      130.7      59.0     493.9   0.0246
 xvar*Athlete     4.1       2.5      10.9       15.8       6.0     106.8   0.0652
 Residual         2.2       1.7       3.2        4.9       2.9      10.2   0.0008


           Effect of subj charac weight on effect of mech var com_x         302
                                  Residuals
                       for second and third trials on each day

                    Plot of Resid*Pred.  Symbol is value of time.
```



```
NOTE: 3 obs hidden.


      Effect of subj charac weight on effect of mech var com_x         303
  Back-transformed least-squares means for work, controlled for weight


                     Effect    time    Estimate


                      time      1        47.8

                      time      2        49.4
```

```
           Effect of subj charac weight on effect of mech var com_x         304
                              Fixed effects (%)

Label                         Estimate   P_value      CLpm     Lower     Upper


time post-pre                    3.46     0.0868      4.12     -0.58      7.66
com_x effect %/unit              0.34     0.2702      0.64     -0.30      0.98
weight*com_x %/unit/unit         0.01     0.2067      0.02     -0.01      0.04
weight*com_x %/unit/SDindiv      0.13     0.2067      0.21     -0.08      0.34



           Effect of subj charac weight on effect of mech var com_x         305
             Back-transformed random effects, expressed as CV (%)

CovParm             CV    CVlow    CVupp   Variance    Lower    Upper    ProbZ


Athlete           12.0      7.9     24.5     128.3      58.1    481.8   0.0242
xvar*Athlete       4.2      2.6     10.8      17.1       6.6    105.3   0.0585
COM_x*Athlete      0.0        .        .       0.0         .        .    .
Residual           2.3      1.7      3.3       5.1       3.0     10.7   0.0009
```

```
             Simple rely analysis for PullAngle (not as %), by time          312
                   Fixed effects (here, the learning effects)

   time      Label      Estimate    P_value       CLpm      Lower      Upper


      1    Trial 2-1        1.7      0.2965        3.5       -1.8        5.2
      1    Trial 3-2         .        .             .          .          .
      2    Trial 2-1        1.1      0.1870        1.7       -0.6        2.8
      2    Trial 3-2         .        .             .          .          .

             Simple rely analysis for PullAngle (not as %), by time          313
              Back-transformed random effects, expressed as raw SD

  time    CovParm         SD     SDlow     SDupp    Variance     Lower     Upper


   1.0    Athlete       9.1       6.1      17.7       83.4       37.8     313.0
   1.0    Residual      3.5       2.4       6.3       12.0        5.7      39.9
   2.0    Athlete       6.8       4.6      12.7       45.8       21.2     160.8
   2.0    Residual      1.7       1.2       3.1        3.0        1.4       9.9


                             Effect of time on work                          314
                                   Residuals
                    for second and third trials on each day


                 Plot of Resid*Pred.  Symbol is value of time.


Resid │
      │
    4 ┼
      │                                                       2
      │
      │                                      2
      │                                                   1              1
      │                                                           1
    2 ┼     1                                          1
      │                                 1
      │                            2           2
      │                            1
      │                         1                                   2    2
      │                       1    1         1                                2
    0 ┼                         2                          2        2
      │    2                                               2                  2
```

```
      │    2                  1                                          2
      │
      │                         2  2           2       1
      │     1                   1                                        1
   -2 ┼                                 1    1                1   1
      │
      │
      │                                                   1
      │
      │
   -4 ┼
      │
      └─┼─────────────┼─────────────┼─────────────┼─────────────┼─────────────┼─
       360           370           380           390           400           410


                                         Pred
NOTE: 1 obs hidden.
                         Effect of time on work                           315
                 Back-transformed least-squares means for work


                           Effect    time    Estimate


                            time      1        47.5
                            time      2        49.7




                             Effect of time on work                           316
                               Fixed effects (%)


         Label      Estimate    P_value       CLpm      Lower      Upper


        post-pre       4.73      0.0115       3.63       1.16       8.42




                             Effect of time on work                           317
              Back-transformed random effects, expressed as CV (%)


 CovParm            CV     CVlow     CVupp   Variance    Lower     Upper     ProbZ


 Athlete          14.2       9.5      27.8     176.5      82.9     600.1    0.0181
 xvar*Athlete      4.9       3.1      11.0      22.7       9.5     108.8    0.0407
 Residual          2.2       1.7       3.2       4.8       2.8      10.0    0.0007
```

```
                          Effect of time on PullAngle                         318
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    6 +
      |
      |                                          1
      |
    4 +                                                           1
      |                                            1
      |
      |                 2       2            2   1              1
    2 +                                               1
      |                          2
      |                     2    21
      |       2     2            1
    0 +             2            1        2
      |                          1                              1 1
      |       2                 2 12      2  2        1
      |                 2   2    2
   -2 +                          11
      |                                            1
      |
      |
   -4 +                                          1
      |
      |                                          1
      |
   -6 +
      |
      +-+-------------+-------------+-------------+-------------+-------------+-
        20            30            40            50            60            70

                                         Pred

NOTE: 3 obs hidden.
```

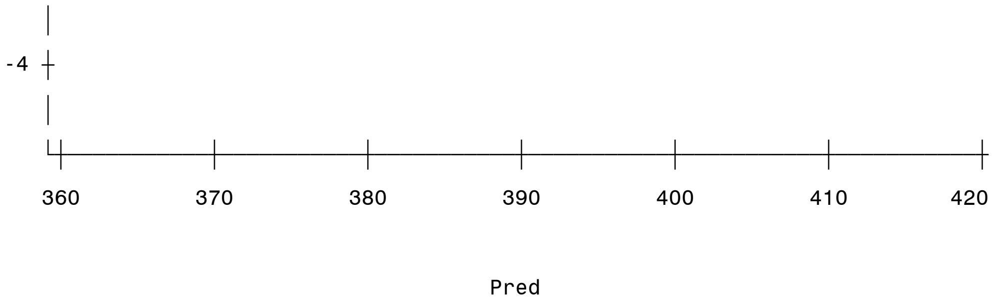
```
                          Effect of time on PullAngle                        319
               Back-transformed least-squares means for PullAngle

                           Effect    time    Estimate

                            time      1        1.604
                            time      2        1.436


                          Effect of time on PullAngle                        320
                               Fixed effects (%)

         Label      Estimate    P_value       CLpm      Lower      Upper

        post-pre      -10.4      0.0001        4.4      -14.7       -5.9


                          Effect of time on PullAngle                        321
              Back-transformed random effects, expressed as CV (%)

 CovParm            CV     CVlow    CVupp   Variance    Lower    Upper    ProbZ

 Athlete           9.3      6.2     18.4      78.6      36.0    285.9   0.0222
 xvar*Athlete      7.2      4.6     15.8      47.7      20.3    214.9   0.0364
 Residual          2.9      2.2      4.3       8.1       4.6     17.4   0.0012

                          Effect of PullAngle on work                        322
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid │
      │
    4 ┼
      │                                                       2
      │
      │
      │                                      2                          1
      │                                                   1
    2 ┼                                        2                   1
      │     1
      │                            2    1              1           2
```

```
      |                            1
      |                                                                  2
      |                        2                           2                 22
    0 +                      1 1    1        1             2
      |    2                      1                                 2
      |                        1                                         2
      |
      |                         2  2        1   2      1
      |                                     2                     1
   -2 +     1
      |                                 1                     2
      |                                                                   1
      |                                                   1
      |
      |
   -4 +
      |
      +-+-------------+-------------+-------------+-------------+-------------+-
       360           370           380           390           400           410


                                         Pred


NOTE: 1 obs hidden.



                          Effect of PullAngle on work                          323
                               Fixed effects (%)


         Label             Estimate    P_value       CLpm      Lower      Upper


PullAngle effect %/unit      -0.19      0.1190       0.25      -0.44       0.06





                          Effect of PullAngle on work                          324
              Back-transformed random effects, expressed as CV (%)


  CovParm                 CV    CVlow   CVupp  Variance   Lower   Upper   ProbZ


  Athlete               14.4      9.0    35.8    181.0     73.7   935.1  0.0461
  xvar*Athlete           5.8      3.8    12.2     31.4     13.6   133.0  0.0321
  PullAngle*Athlete      0.0      0.0      .       0.0      0.0   4E274  0.4698
  Residual               2.2      1.7     3.3      4.8      2.8    10.4  0.0012
```

```
                      Effect of time and PullAngle on work                   325
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |                                                       2
      |
      |
      |                                      2            1
      |                                                           1      1
    2 +     1                                          1
      |                                 1      2
      |                            2
      |                            1
      |                                                            2     2
      |                       1  1 1         1                                2
    0 +                         2                          2
      |                       1                            2        2         2
      |    2                                                             2
      |
      |                         1               2      1
      |     1                      2        1                            1
   -2 +                                 1    2                2   1
      |
      |
      |                                                   1
      |
      |
   -4 +
      |
      +-+-------------+-------------+-------------+-------------+-------------+-
       360           370           380           390           400           410

                                         Pred

NOTE: 2 obs hidden.
```

```
                      Effect of time and PullAngle on work                   326
    Back-transformed least-squares means for work, controlled for PullAngle


                           Effect    time    Estimate


                            time      1        47.6
                            time      2        49.6
                      Effect of time and PullAngle on work                   327
                               Fixed effects (%)


Label                      Estimate    P_value       CLpm      Lower      Upper


time post-pre                 4.34      0.0884       5.24      -0.76       9.71
PullAngle effect %/unit      -0.03      0.8398       0.31      -0.34       0.28



                      Effect of time and PullAngle on work                   328
              Back-transformed random effects, expressed as CV (%)


  CovParm                CV   CVlow   CVupp  Variance   Lower   Upper   ProbZ


  Athlete              14.0     9.0    31.4    171.7     73.9   744.8  0.0338
  xvar*Athlete          5.0     3.1    12.0     23.5      9.4   127.8  0.0498
  PullAngle*Athlete     0.1     0.0      .       0.0      0.0  133E47  0.4308
  Residual              2.2     1.7     3.3      4.8      2.8    10.5  0.0012
```

```
                       Effect of time and weight on work                     329
                        Univariate statistics for weight

                              The MEANS Procedure
                           Analysis Variable : Weight

        N            Mean         Std Dev         Minimum         Maximum
       ------------------------------------------------------------------
       10           104.7             8.9            95.4           120.1
       ------------------------------------------------------------------


                       Effect of time and weight on work                     330
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |
      |                                               2
      |                                2                      1
      |                                           1      1
      |
    2 +   1                                    1
      |                                  2
      |                       2    1
      |                       1                           2
      |                                                        2
      |                   1 1 1       1                   2
    0 +                    2                       2
      |   2                                        2               2
      |                   1
      |                                  2                     2   2
      |                    2  2                1              1
      |   1                            2                 1
   -2 +                     1      1  1
      |                                               2
      |
      |
      |                                           1
```



```
NOTE: 1 obs hidden.



                       Effect of time and weight on work                     331
      Back-transformed least-squares means for work, controlled for weight


                           Effect    time    Estimate


                            time      1        47.5
                            time      2        49.7
                       Effect of time and weight on work                     332
                               Fixed effects (%)


Label                               Estimate   P_value      CLpm     Lower     Upper


time post-pre                          4.74     0.0043      3.14      1.65      7.93
weight indiv responses %/unit          0.33     0.0682      0.35     -0.03      0.68



                       Effect of time and weight on work                     333
              Back-transformed random effects, expressed as CV (%)


 CovParm            CV     CVlow     CVupp   Variance     Lower     Upper     ProbZ


 Athlete          12.1       8.0      24.9      130.7      59.0     493.9    0.0246
 xvar*Athlete      4.1       2.5      10.9       15.8       6.0     106.8    0.0652
 Residual          2.2       1.7       3.2        4.9       2.9      10.2    0.0008



          Effect of subj charac weight on effect of mech var PullAngle       334
                                   Residuals
                      for second and third trials on each day


                   Plot of Resid*Pred.  Symbol is value of time.


Resid |
```

```
      |
    4 +
      |
      |                                                       2
      |
      |                                       2           1
      |                                                           1
    2 +     1                                                            1
      |                                 1      2       1
      |
      |                            1                                     2
      |                                     1                      2         2
      |                       1  1
    0 +                      1 2    1                      2
      |    2                                               2        2
      |    2                                                             2    2
      |                        1
      |                         2              2      1                1
      |     1                      2
   -2 +                                 1   12                2   1
      |
      |                                                  1
      |
      |
      |
   -4 +
      |
      +-+-------------+-------------+-------------+-------------+-------------+-
       360           370           380           390           400           410

                                         Pred

NOTE: 1 obs hidden.

          Effect of subj charac weight on effect of mech var PullAngle       335
      Back-transformed least-squares means for work, controlled for weight

                           Effect    time    Estimate

                            time      1        47.6
                            time      2        49.5
```

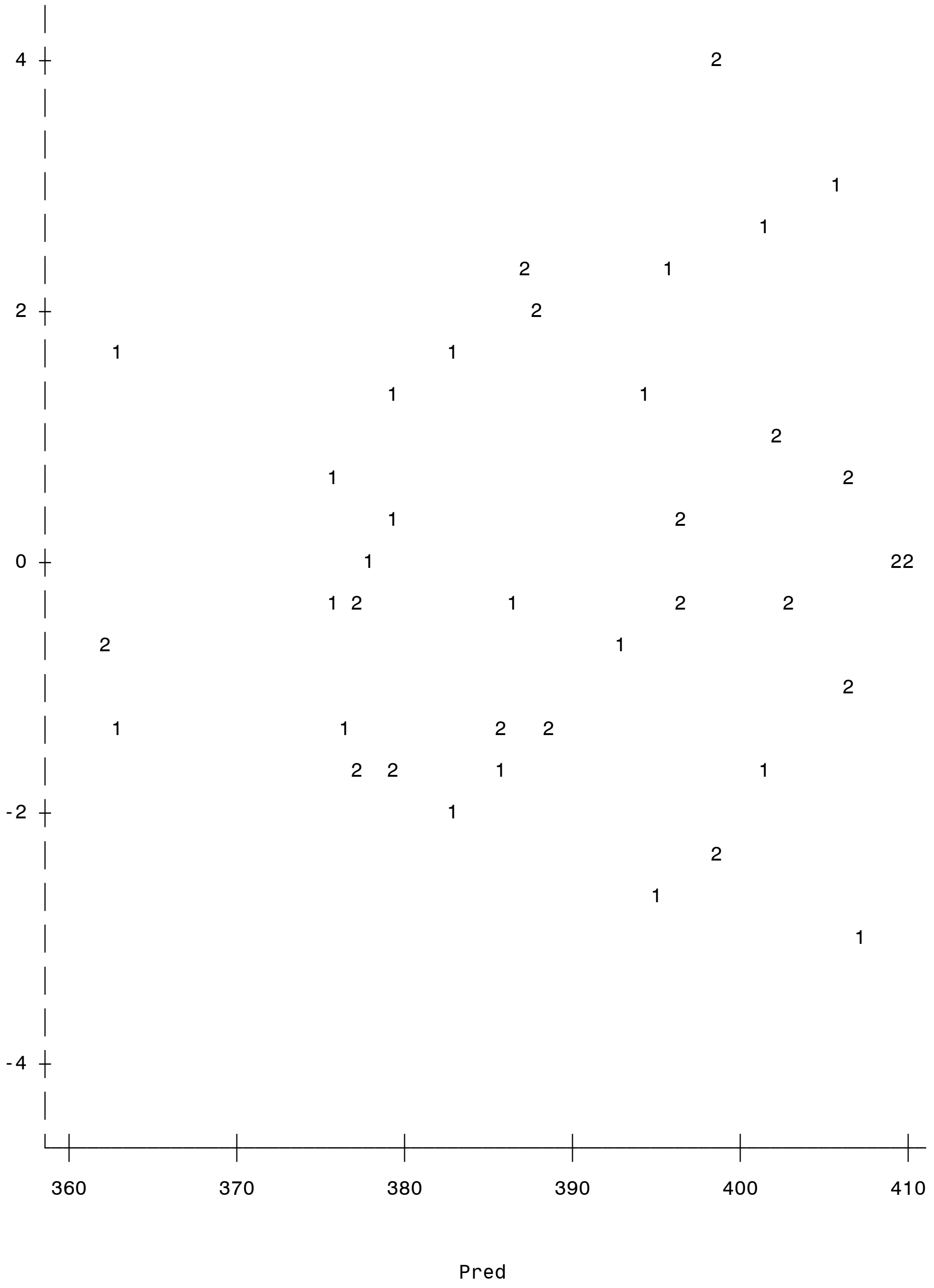
```
         Effect of subj charac weight on effect of mech var PullAngle       336
                             Fixed effects (%)

Label                             Estimate  P_value     CLpm    Lower    Upper


time post-pre                         4.00   0.1419     5.70    -1.55     9.86
PullAngle effect %/unit              -0.05   0.7594     0.33    -0.37     0.28
weight*PullAngle %/unit/unit          0.01   0.3660     0.02    -0.01     0.03
weight*PullAngle %/unit/SDindiv       0.07   0.3660     0.17    -0.10     0.24
```

```
         Effect of subj charac weight on effect of mech var PullAngle       337
             Back-transformed random effects, expressed as CV (%)

 CovParm                 CV    CVlow   CVupp  Variance   Lower   Upper   ProbZ


 Athlete               12.1      7.0    41.1     130.6    45.9  1183.5  0.0847
 xvar*Athlete           5.8      3.4    16.6      31.3    11.5   236.4  0.0728
 PullAngle*Athlete      0.1      0.0  499E18       0.0     0.0  1.85E7  0.3430
 Residual               2.2      1.7     3.2       4.7     2.7    10.1  0.0011
```

```
                       Effect of time and height on work                     233
                        Univariate statistics for height

                              The MEANS Procedure
                           Analysis Variable : Height

        N            Mean         Std Dev         Minimum         Maximum
       ──────────────────────────────────────────────────────────────────
       10           187.5             7.2           176.3           201.0
       ──────────────────────────────────────────────────────────────────
```

```
                       Effect of time and height on work                     234
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |                                                       2
      |
      |
      |                                      2            1             1
      |                                                           1
    2 +     1                                          1
      |                                        2
      |                            2    1
      |                            1
      |                         1                                   2    2
      |                       1    1         1
    0 +                        2                           2        2
      |    2                                                                  2
      |    2                  1                                          2    2
      |                                        2
      |                        2   2                   1
      |     1                   1                                       1
   -2 +                                 1    1                2   1
      |
      |
      |                                                   1
      |
```

```
      |
   -4 +
      |
      |
      +-+-------------+-------------+-------------+-------------+-------------+-
       360           370           380           390           400           410

                                           Pred
NOTE: 2 obs hidden.



                       Effect of time and height on work                     235
      Back-transformed least-squares means for work, controlled for height


                           Effect    time    Estimate


                            time      1        47.5

                            time      2        49.7
                       Effect of time and height on work                     236
                               Fixed effects (%)


Label                           Estimate   P_value      CLpm     Lower     Upper


time post-pre                      4.73     0.0091      3.49      1.29      8.28

height indiv responses %/unit      0.29     0.2250      0.49     -0.20      0.79



                       Effect of time and height on work                     237
              Back-transformed random effects, expressed as CV (%)


 CovParm             CV     CVlow     CVupp   Variance     Lower     Upper     ProbZ


 Athlete           13.0       8.6      26.8      149.5      67.6     562.6    0.0244

 xvar*Athlete       4.7       2.9      11.5       20.7       8.2     118.7    0.0535

 Residual           2.2       1.7       3.2        4.9       2.8      10.1    0.0008



            Effect of subj charac height on effect of mech var com_x         238
                                   Residuals
                       for second and third trials on each day


                     Plot of Resid*Pred.  Symbol is value of time.


Resid |
```



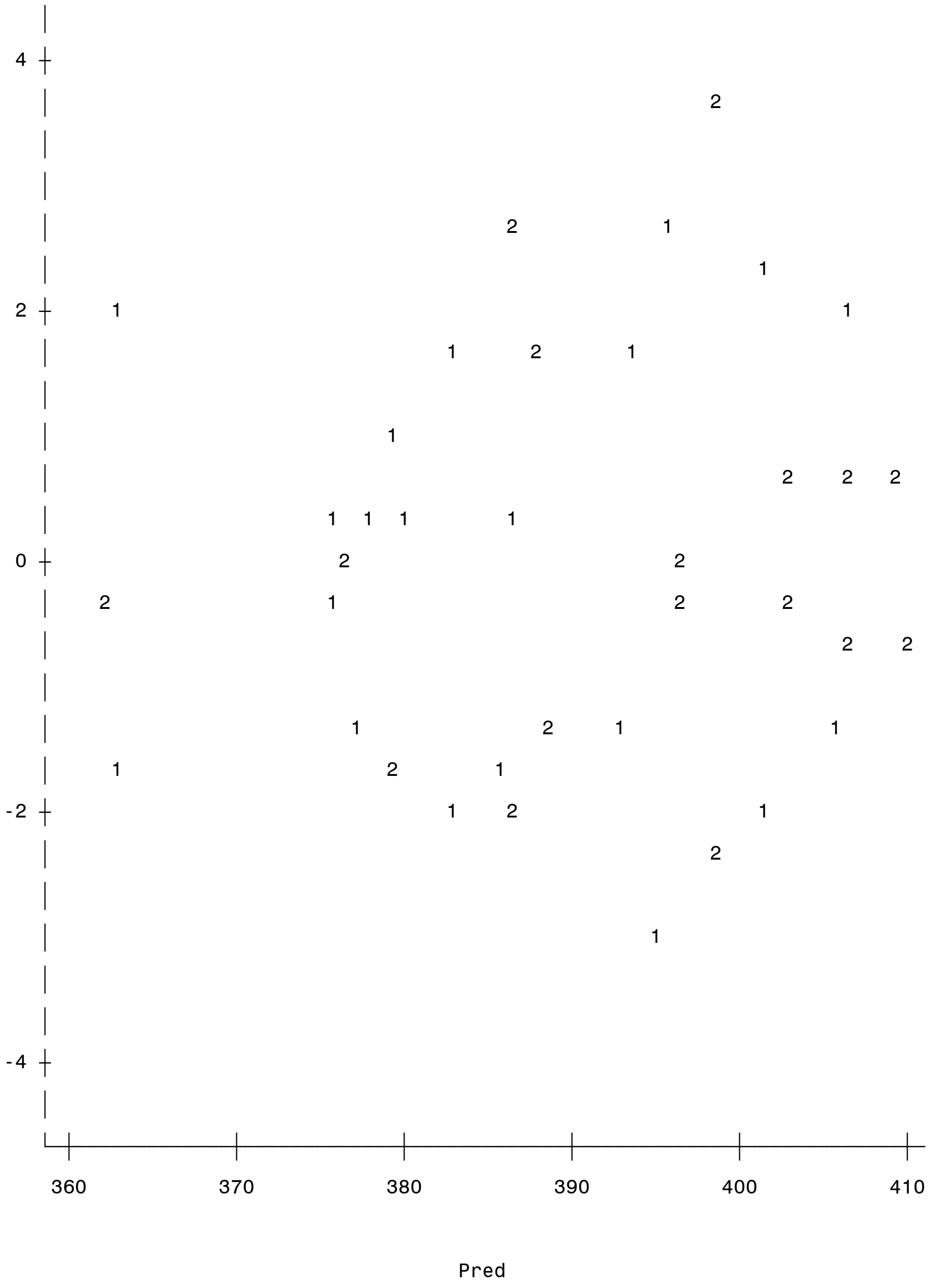
```
NOTE: 2 obs hidden.


          Effect of subj charac height on effect of mech var com_x        239
     Back-transformed least-squares means for work, controlled for height


                         Effect    time    Estimate


                          time      1        47.8
                          time      2        49.4
```

```
           Effect of subj charac height on effect of mech var com_x         240
                              Fixed effects (%)

Label                         Estimate   P_value      CLpm     Lower     Upper


time post-pre                    3.37     0.0997      4.21     -0.75      7.67
com_x effect %/unit              0.37     0.2193      0.63     -0.26      1.01
height*com_x %/unit/unit         0.02     0.2487      0.03     -0.01      0.05
height*com_x %/unit/SDindiv      0.12     0.2487      0.21     -0.10      0.33



           Effect of subj charac height on effect of mech var com_x         241
             Back-transformed random effects, expressed as CV (%)

CovParm             CV    CVlow    CVupp   Variance    Lower    Upper    ProbZ


Athlete           12.3      8.1     25.3     134.1      60.5    509.0   0.0249
xvar*Athlete       4.4      2.7     10.7      18.2       7.2    102.7   0.0523
COM_x*Athlete      0.0        .        .       0.0         .        .     .
Residual           2.2      1.7      3.3       4.9       2.9     10.4   0.0009
```

```
                       Effect of time and height on work                     265
                        Univariate statistics for height

                              The MEANS Procedure
                           Analysis Variable : Height

        N            Mean         Std Dev         Minimum         Maximum
       ------------------------------------------------------------------
       10           187.5             7.2           176.3           201.0
       ------------------------------------------------------------------
```

```
                       Effect of time and height on work                     266
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |                                                       2
      |
      |
      |                                      2            1             1
      |                                                           1
    2 +     1                                          1
      |                                        2
      |                            2    1
      |                            1
      |                         1                                   2    2
      |                       1    1         1
    0 +                        2                           2        2
      |    2                                                                  2
      |    2                  1                                          2    2
      |                                        2
      |                        2   2                   1
      |     1                   1                                       1
   -2 +                                 1    1                2   1
      |
      |
      |                                                   1
      |
```

```
      |
   -4 +
      |
      └-+-------------+-------------+-------------+-------------+-------------+-
       360           370           380           390           400           410


                                         Pred
NOTE: 2 obs hidden.



                       Effect of time and height on work                     267
      Back-transformed least-squares means for work, controlled for height


                           Effect    time    Estimate


                            time      1        47.5
                            time      2        49.7
                       Effect of time and height on work                     268
                               Fixed effects (%)


Label                           Estimate   P_value      CLpm     Lower     Upper


time post-pre                      4.73     0.0091      3.49      1.29      8.28
height indiv responses %/unit      0.29     0.2250      0.49     -0.20      0.79



                       Effect of time and height on work                     269
              Back-transformed random effects, expressed as CV (%)


 CovParm            CV     CVlow     CVupp   Variance     Lower     Upper    ProbZ


 Athlete          13.0       8.6      26.8      149.5      67.6     562.6   0.0244
 xvar*Athlete      4.7       2.9      11.5       20.7       8.2     118.7   0.0535
 Residual          2.2       1.7       3.2        4.9       2.8      10.1   0.0008



          Effect of subj charac height on effect of mech var PullAngle       270
                                   Residuals
                    for second and third trials on each day


                 Plot of Resid*Pred.  Symbol is value of time.


Resid |
```



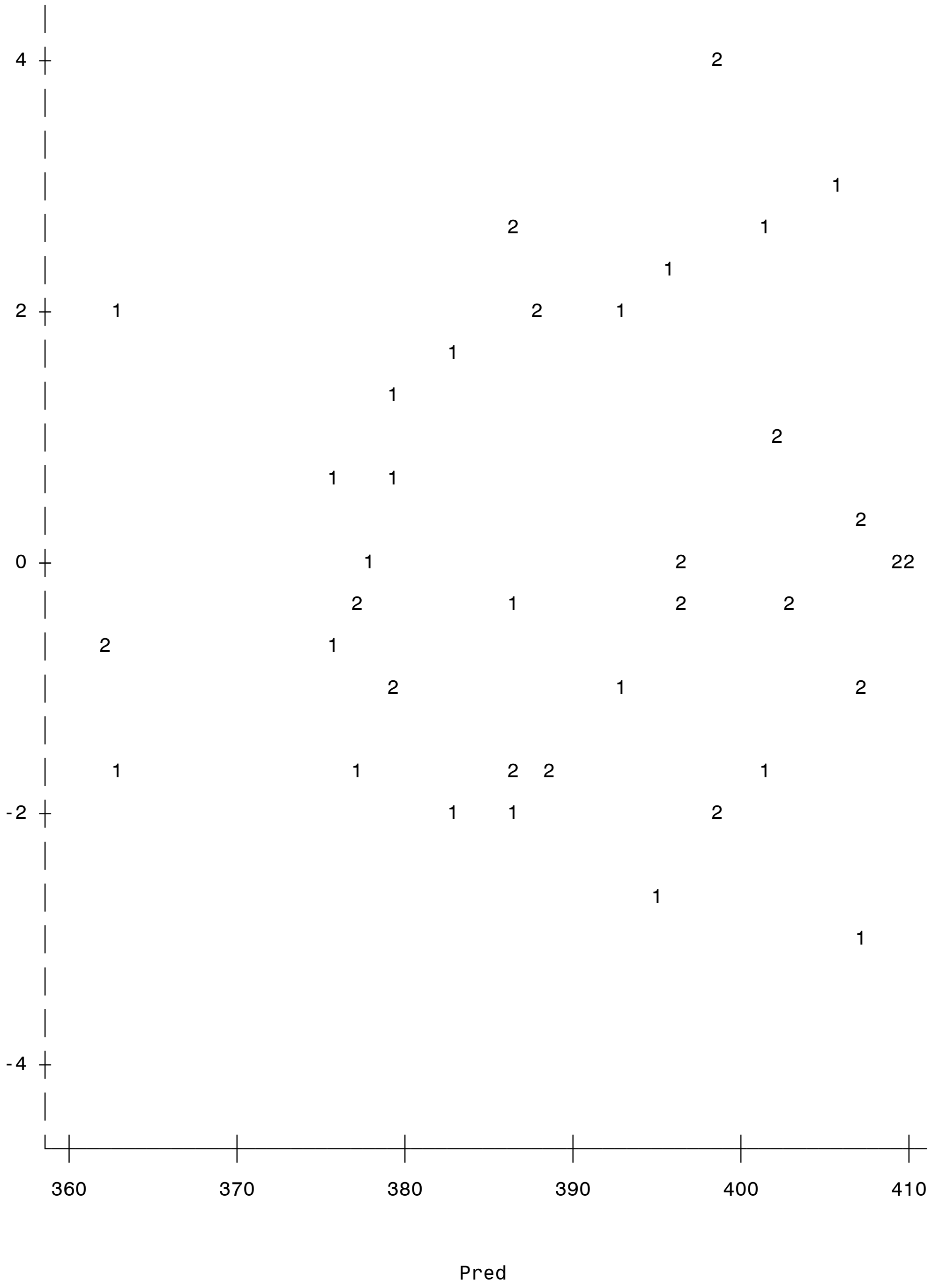
```
NOTE: 3 obs hidden.


        Effect of subj charac height on effect of mech var PullAngle       271
    Back-transformed least-squares means for work, controlled for height


                            Effect    time    Estimate


                             time      1        47.6
                             time      2        49.5
```

```
         Effect of subj charac height on effect of mech var PullAngle       272
                              Fixed effects (%)

Label                            Estimate  P_value     CLpm    Lower    Upper


time post-pre                        4.05    0.1324     5.65    -1.45     9.85
PullAngle effect %/unit             -0.05    0.7611     0.33    -0.38     0.29
height*PullAngle %/unit/unit         0.01    0.4646     0.03    -0.02     0.03
height*PullAngle %/unit/SDindiv      0.06    0.4646     0.19    -0.12     0.25
```

```
         Effect of subj charac height on effect of mech var PullAngle       273
             Back-transformed random effects, expressed as CV (%)

 CovParm                CV    CVlow    CVupp  Variance   Lower    Upper   ProbZ


 Athlete              12.8      7.7     36.9     144.5    54.4    987.2  0.0658
 xvar*Athlete          5.5      3.3     14.9      28.3    10.6    193.1  0.0658
 PullAngle*Athlete     0.1      0.0    1E299       0.0     0.0   4.68E9  0.3594
 Residual              2.2      1.7      3.3       4.8     2.8     10.3  0.0011
```

```
                      Effect of time and BenchPull on work                   361
                      Univariate statistics for BenchPull

                              The MEANS Procedure
                         Analysis Variable : BenchPull

        N            Mean         Std Dev         Minimum         Maximum
       ──────────────────────────────────────────────────────────────────
       10           114.8            10.6            96.0           129.0
       ──────────────────────────────────────────────────────────────────


                      Effect of time and BenchPull on work                   362
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |                                                       2
      |
      |                                      2
      |                                                  1        1     1
      |
    2 +                                               1
      |     1                     2     1
      |                                         2
      |                            1
      |                            1                                2    2
      |                       1  1           1
    0 +                         2                          2                  2
      |    2                                                        2
      |                       1                                               2
      |                           2                                      2
      |                         2               2     1                 1
      |     1                                                    1
   -2 +                          1      1    2                2
      |                                      1
      |
      |                                                  1
      |
```

```
      │
   -4 ┼
      │
      └─┼─────────────┼─────────────┼─────────────┼─────────────┼─────────────┼─
       360           370           380           390           400           410

                                      Pred
NOTE: 2 obs hidden.



                       Effect of time and BenchPull on work                   363
    Back-transformed least-squares means for work, controlled for BenchPull


                             Effect    time    Estimate


                              time      1        47.5
                              time      2        49.7
                       Effect of time and BenchPull on work                   364
                                Fixed effects (%)


 Label                            Estimate  P_value     CLpm    Lower    Upper


 time post-pre                        4.73    0.0065     3.32     1.46     8.10
 BenchPull indiv responses %/unit     0.23    0.1441     0.32    -0.09     0.55



                       Effect of time and BenchPull on work                   365
              Back-transformed random effects, expressed as CV (%)


 CovParm            CV    CVlow    CVupp   Variance    Lower    Upper    ProbZ


 Athlete           8.7      5.8     18.0       70.2     31.4    272.6   0.0264
 xvar*Athlete      4.4      2.7     11.2       18.2      7.0    113.1   0.0594
 Residual          2.2      1.7      3.3        4.9      2.9     10.4   0.0009



            Effect of subj charac BenchPull on effect of mech var com_x        366
                                    Residuals
                       for second and third trials on each day


                   Plot of Resid*Pred.  Symbol is value of time.


Resid │
```

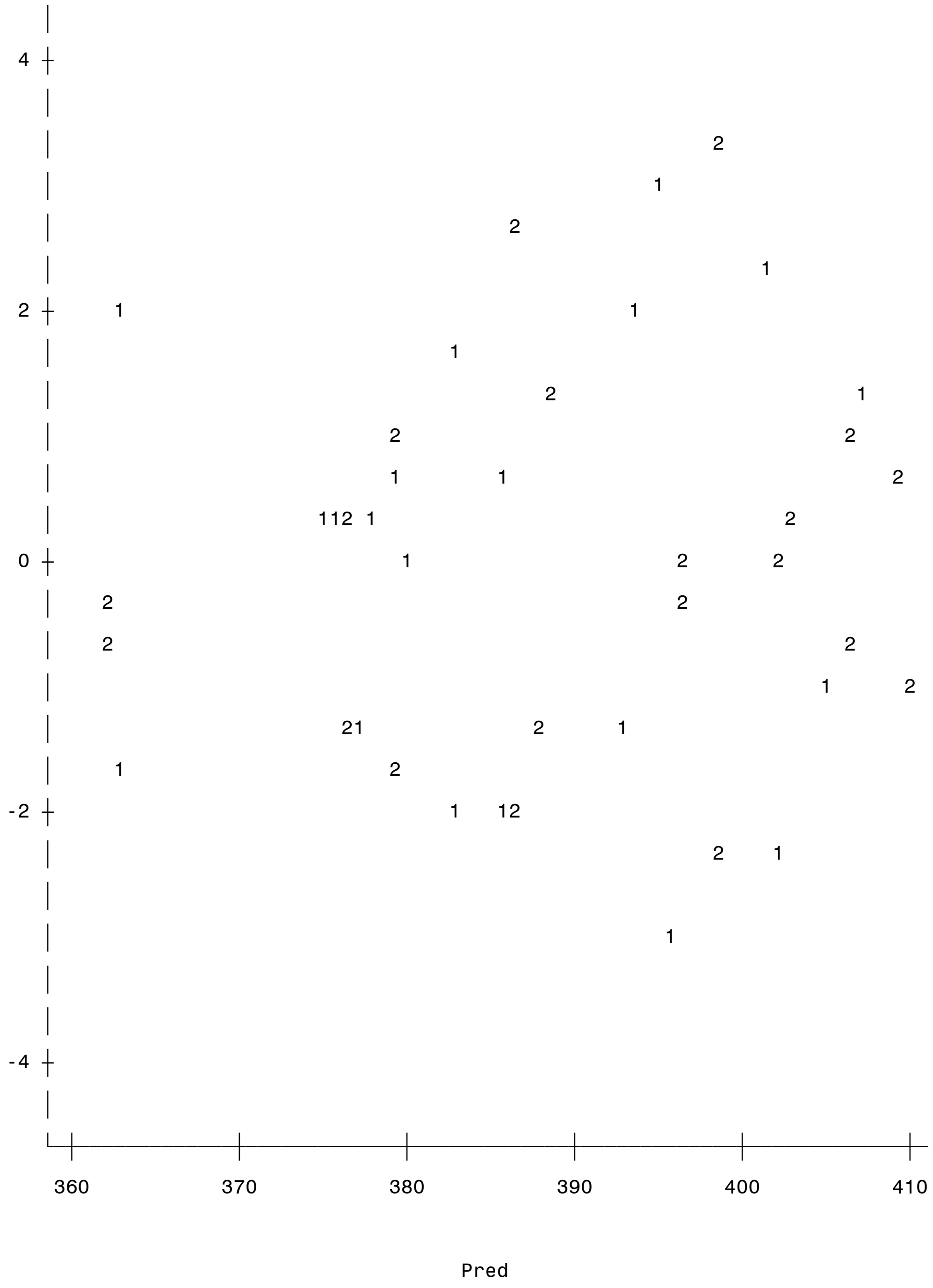


```
NOTE: 3 obs hidden.


         Effect of subj charac BenchPull on effect of mech var com_x        367
    Back-transformed least-squares means for work, controlled for BenchPull


                         Effect    time    Estimate


                          time      1        47.6
                          time      2        49.6
```

```
         Effect of subj charac BenchPull on effect of mech var com_x       368
                              Fixed effects (%)

 Label                           Estimate  P_value     CLpm    Lower    Upper


 time post-pre                       4.10   0.0417     3.99     0.18     8.17
 com_x effect %/unit                 0.20   0.4364     0.55    -0.35     0.76
 BenchPull*com_x %/unit/unit         0.02   0.0080     0.02     0.01     0.04
 BenchPull*com_x %/unit/SDindiv      0.26   0.0080     0.18     0.08     0.44



         Effect of subj charac BenchPull on effect of mech var com_x       369
             Back-transformed random effects, expressed as CV (%)

CovParm             CV    CVlow    CVupp   Variance    Lower    Upper    ProbZ


Athlete            8.2      5.3     17.1      61.5      27.1    249.4   0.0293
xvar*Athlete       4.2      2.6     10.5      17.0       6.6    100.3   0.0557
COM_x*Athlete      0.0       .        .        0.0        .        .     .
Residual           2.3      1.7      3.4       5.2       3.0     11.0   0.0010
```

```
                      Effect of time and BenchPull on work                   393
                      Univariate statistics for BenchPull

                              The MEANS Procedure
                         Analysis Variable : BenchPull

        N            Mean         Std Dev         Minimum         Maximum
       ──────────────────────────────────────────────────────────────────
       10           114.8            10.6            96.0           129.0
       ──────────────────────────────────────────────────────────────────



                      Effect of time and BenchPull on work                   394
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |                                                       2
      |
      |                                      2
      |                                                  1        1     1
      |
    2 +                                                 1
      |     1                     2     1
      |                                         2
      |                            1
      |                            1                                2    2
      |                       1  1           1
    0 +                         2                          2                  2
      |    2                                                        2
      |                       1                                               2
      |                           2                                      2
      |                         2               2     1                 1
      |     1                                                     1
   -2 +                          1      1    2                2
      |                                      1
      |
      |                                                  1
      |
```

```
      │
   -4 ┼
      │
      └─┼─────────────┼─────────────┼─────────────┼─────────────┼─────────────┼─
       360           370           380           390           400           410


                                         Pred
NOTE: 2 obs hidden.



                      Effect of time and BenchPull on work                   395
    Back-transformed least-squares means for work, controlled for BenchPull


                           Effect    time    Estimate


                            time      1        47.5
                            time      2        49.7
                      Effect of time and BenchPull on work                   396
                               Fixed effects (%)


 Label                             Estimate  P_value     CLpm    Lower    Upper


 time post-pre                        4.73    0.0065     3.32     1.46     8.10
 BenchPull indiv responses %/unit     0.23    0.1441     0.32    -0.09     0.55



                      Effect of time and BenchPull on work                   397
              Back-transformed random effects, expressed as CV (%)


 CovParm            CV     CVlow    CVupp   Variance    Lower    Upper    ProbZ


 Athlete           8.7       5.8     18.0       70.2     31.4    272.6   0.0264
 xvar*Athlete      4.4       2.7     11.2       18.2      7.0    113.1   0.0594
 Residual          2.2       1.7      3.3        4.9      2.9     10.4   0.0009



        Effect of subj charac BenchPull on effect of mech var PullAngle      398
                                   Residuals
                    for second and third trials on each day


                 Plot of Resid*Pred.  Symbol is value of time.


Resid │
```



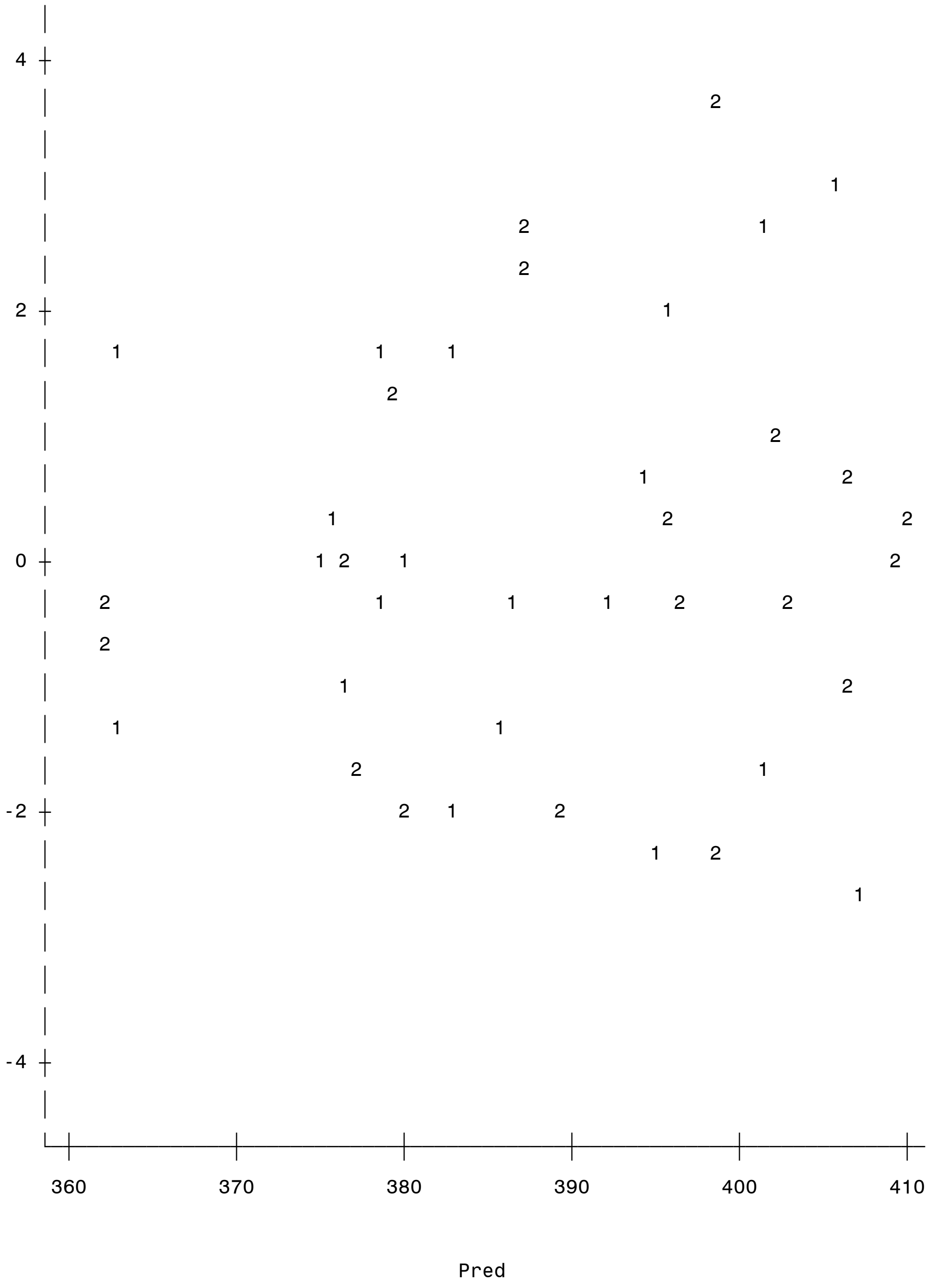
```
    Effect of subj charac BenchPull on effect of mech var PullAngle      399
Back-transformed least-squares means for work, controlled for BenchPull


                      Effect    time    Estimate


                       time      1        47.6
                       time      2        49.5
```

```
        Effect of subj charac BenchPull on effect of mech var PullAngle      400
                               Fixed effects (%)

Label                               Estimate  P_value     CLpm    Lower    Upper


time post-pre                          4.00    0.1582     5.97    -1.79    10.14
PullAngle effect %/unit               -0.00    0.9755     0.33    -0.33     0.32
BenchPull*PullAngle %/unit/unit        0.01    0.0428     0.01     0.00     0.03
BenchPull*PullAngle %/unit/SDindiv     0.15    0.0428     0.14     0.01     0.29



        Effect of subj charac BenchPull on effect of mech var PullAngle      401
              Back-transformed random effects, expressed as CV (%)

  CovParm                CV   CVlow   CVupp  Variance   Lower   Upper   ProbZ


  Athlete               8.9     4.8    47.7      73.2    21.8  1521.6  0.1311
  xvar*Athlete          6.3     4.0    15.0      37.5    15.2   194.6  0.0465
  PullAngle*Athlete     0.1     0.0    69.0       0.0     0.0  2753.0  0.2987
  Residual              2.2     1.7     3.3       4.8     2.8    10.5  0.0012
```

```
                     Effect of time and BrachIndex on work                   425
                      Univariate statistics for BrachIndex

                              The MEANS Procedure
                         Analysis Variable : BrachIndex

        N            Mean         Std Dev         Minimum         Maximum
       ──────────────────────────────────────────────────────────────────
       10            80.1             2.5            76.4            83.5
       ──────────────────────────────────────────────────────────────────
```

```
                     Effect of time and BrachIndex on work                   426
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |                                                       2
      |
      |                                      2
      |                                                   1
      |                                                           1      1
    2 +     1                                          1
      |                                 1
      |                            2            2
      |                            1
      |                         1                                   2    2
      |                       1    1        1                                2
    0 +                         2                          2
      |    2                                               2        2        2
      |                       1                                          2
      |
      |                         2  2            2      1
      |     1                   1
   -2 +                                 1   12                2   1      1
      |
      |
      |                                                   1
      |
```

```
      │
   -4 ┼
      │
      └─┼─────────────┼─────────────┼─────────────┼─────────────┼─────────────┼─
       360           370           380           390           400           410


                                         Pred
NOTE: 1 obs hidden.



                     Effect of time and BrachIndex on work                   427
    Back-transformed least-squares means for work, controlled for BrachIndex


                           Effect    time    Estimate


                            time      1        47.5
                            time      2        49.7
                     Effect of time and BrachIndex on work                   428
                               Fixed effects (%)


Label                              Estimate  P_value     CLpm    Lower    Upper


time post-pre                         4.72    0.0165     3.85     0.94     8.64
BrachIndex indiv responses %/unit     0.15    0.8429     1.57    -1.40     1.73



                     Effect of time and BrachIndex on work                   429
              Back-transformed random effects, expressed as CV (%)


 CovParm            CV    CVlow     CVupp   Variance     Lower     Upper     ProbZ


 Athlete          15.1      9.9      31.3      198.5      89.9     742.9    0.0240
 xvar*Athlete      5.2      3.3      12.3       26.0      10.6     134.6    0.0464
 Residual          2.2      1.7       3.2        4.8       2.8      10.0    0.0007



          Effect of subj charac BrachIndex on effect of mech var com_x       430
                                   Residuals
                    for second and third trials on each day


                 Plot of Resid*Pred.  Symbol is value of time.


Resid │
```



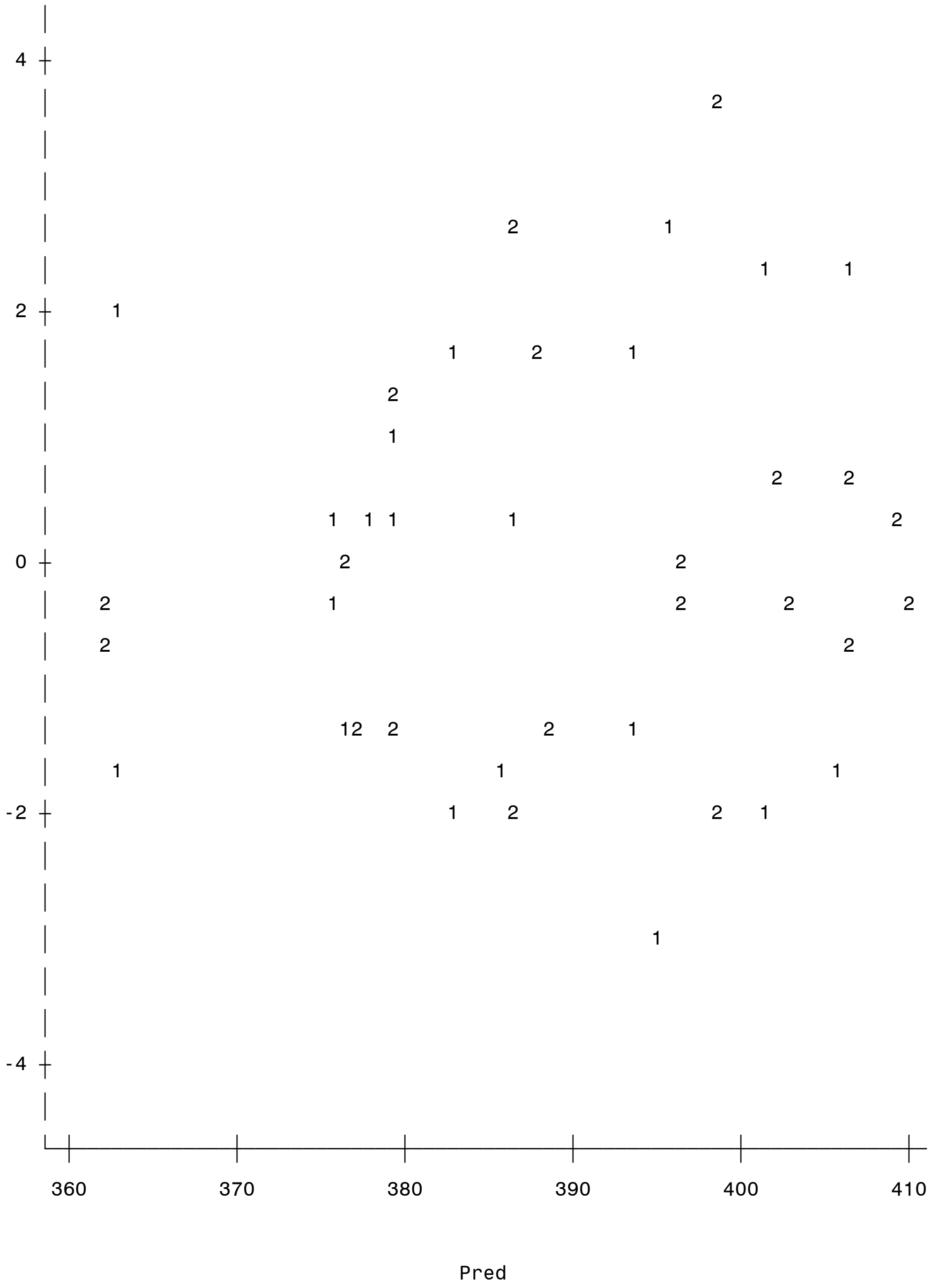
```
NOTE: 1 obs hidden.


          Effect of subj charac BrachIndex on effect of mech var com_x       431
    Back-transformed least-squares means for work, controlled for BrachIndex


                          Effect    time    Estimate


                           time      1        48.0
                           time      2        49.2
```

```
         Effect of subj charac BrachIndex on effect of mech var com_x       432
                              Fixed effects (%)

Label                            Estimate  P_value     CLpm    Lower    Upper


time post-pre                       2.67    0.1893     4.28    -1.52     7.04
com_x effect %/unit                 0.56    0.0643     0.60    -0.04     1.16
BrachIndex*com_x %/unit/unit        0.01    0.7314     0.09    -0.08     0.11
BrachIndex*com_x %/unit/SDindiv     0.04    0.7314     0.23    -0.20     0.27



         Effect of subj charac BrachIndex on effect of mech var com_x       433
                 Back-transformed random effects, expressed as CV (%)

CovParm             CV     CVlow    CVupp   Variance    Lower    Upper    ProbZ


Athlete           12.5       8.2     26.7      139.0     61.4    559.3   0.0287
xvar*Athlete       4.7       3.0     10.8       20.8      8.5    105.4   0.0446
COM_x*Athlete      0.0        .        .         0.0       .        .      .
Residual           2.3       1.7      3.3        5.0      2.9     10.6   0.0010
```

```
                     Effect of time and BrachIndex on work                   457
                      Univariate statistics for BrachIndex


                              The MEANS Procedure
                         Analysis Variable : BrachIndex

        N             Mean         Std Dev         Minimum         Maximum
       ──────────────────────────────────────────────────────────────────
       10             80.1             2.5            76.4            83.5
       ──────────────────────────────────────────────────────────────────
```

```
                     Effect of time and BrachIndex on work                   458
                                   Residuals
                    for second and third trials on each day

                 Plot of Resid*Pred.  Symbol is value of time.

Resid |
      |
    4 +
      |                                                       2
      |
      |                                      2
      |                                                   1
      |                                                           1      1
    2 +     1                                          1
      |                                 1
      |                            2            2
      |                            1
      |                         1                                   2    2
      |                       1    1        1                                2
    0 +                         2                          2
      |    2                                               2        2        2
      |                       1                                          2
      |
      |                         2  2            2      1
      |     1                   1
   -2 +                                 1   12                2   1      1
      |
      |
      |                                                   1
      |
```

```
      |
   -4 +
      |
      |
      --+-------------+-------------+-------------+-------------+-------------+-
       360           370           380           390           400           410

                                            Pred
NOTE: 1 obs hidden.



                    Effect of time and BrachIndex on work                  459
    Back-transformed least-squares means for work, controlled for BrachIndex


                          Effect    time    Estimate


                           time      1        47.5
                           time      2        49.7
                    Effect of time and BrachIndex on work                  460
                                Fixed effects (%)


Label                              Estimate  P_value     CLpm    Lower    Upper


time post-pre                         4.72    0.0165     3.85     0.94     8.64
BrachIndex indiv responses %/unit     0.15    0.8429     1.57    -1.40     1.73



                    Effect of time and BrachIndex on work                  461
              Back-transformed random effects, expressed as CV (%)


 CovParm            CV     CVlow     CVupp    Variance     Lower     Upper     ProbZ


 Athlete          15.1       9.9      31.3      198.5       89.9     742.9    0.0240
 xvar*Athlete      5.2       3.3      12.3       26.0       10.6     134.6    0.0464
 Residual          2.2       1.7       3.2        4.8        2.8      10.0    0.0007



        Effect of subj charac BrachIndex on effect of mech var PullAngle     462
                                   Residuals
                      for second and third trials on each day


                   Plot of Resid*Pred.  Symbol is value of time.


Resid |
```



```
    Effect of subj charac BrachIndex on effect of mech var PullAngle     463
Back-transformed least-squares means for work, controlled for BrachIndex


                       Effect    time    Estimate


                        time      1        47.6
                        time      2        49.6
```

```
      Effect of subj charac BrachIndex on effect of mech var PullAngle     464
                            Fixed effects (%)

Label                                Estimate P_value    CLpm   Lower   Upper


time post-pre                            4.30  0.0935    5.29   -0.85    9.72
PullAngle effect %/unit                 -0.04  0.8068    0.31   -0.35    0.28
BrachIndex*PullAngle %/unit/unit        -0.02  0.6629    0.08   -0.09    0.06
BrachIndex*PullAngle %/unit/SDindiv     -0.04  0.6629    0.20   -0.24    0.16



      Effect of subj charac BrachIndex on effect of mech var PullAngle     465
            Back-transformed random effects, expressed as CV (%)

CovParm                CV    CVlow    CVupp  Variance   Lower    Upper   ProbZ


Athlete              14.4      9.2     32.6     180.2    77.1    796.1  0.0351
xvar*Athlete          5.0      3.1     12.6      24.2     9.5    141.3  0.0548
PullAngle*Athlete     0.1      0.0      .         0.0     0.0   114E23  0.4058
Residual              2.2      1.7      3.3       4.8     2.8     10.3  0.0011
```

Appendix 9: Details of individual non-uniform results.

Subject 1 exhibited substantial non-uniform changes in shoulder$_y$ position, COM$_y$ position, COM$_x$ range of movement, COM vector magnitude, and COM vector angle; which significantly increased (p = .022) where it was hoped to decrease. A number of these occurrences are interlinked and fortunately are reasonably easy to explain. As a result of the intervention, subject 1 moved his trunk into a more upright position, which increased the vertical distance between the hip joint and the shoulder joint. Unlike many of the grinder operators who were also lowering their overall body position as part of this adjustment, the body position of subject 1 remained fairly level - as indicated by the low level of change in hip$_y$ position. The function of the reduction in trunk angle was therefore to raise the shoulder$_y$ position that in turn raised the COM$_y$ position. Elevating the COM position also had the effect of raising the COM vector angle, especially since the increase in COM$_y$ position (3 cm) was greater than the increase in COM$_x$ position (1 cm). At 176 cm in height subject 1 was the shortest grinder operator in this study by 6 cm, and the only one to be more than one standard deviation below the group mean (188.0 ± 7.0 cm). Because his COM was located below the grinder hub a rise in the COM vector angle actually brought his COM vertically closer to the hub. As there was no real increase in the COM$_x$ distance from the hub, this resulted in a decrease in the magnitude of the COM vector. The final non-uniform variable for subject 1 - COM$_x$ range of movement - is unfortunately more difficult to explain. A possible explanation is that the previously mentioned rise in shoulder$_y$ position meant that the main pull movement moved into a slightly more vertical path, which could decrease the horizontal displacement of the body in general. However, although this possibility was supported by the increase in the COM and shoulder vector angles, it was contradicted by a decrease in the COM$_y$ and shoulder$_y$ and ranges of movement; so the exact reason for the decrease in COM$_x$ range of movement was unclear.

Only three substantially non-uniform changes were seen in subject 2, but of these, two (shoulder$_y$ range of movement and shoulder vector magnitude) were statistically significant, with the other variable being COM$_y$ range of movement. Subject 2 originally drew attention to his results by being one of the only grinder operators (along with subject 11) to exhibit a decrease in grinding performance following the intervention, this was despite the majority of his kinematic changes occurring in the desired direction. On a qualitative review of the video footage, it appeared that the body position of subject 2 had actually ended up too low following the intervention. The intended result was to achieve a balanced position with the body weight shifted back, the shoulder approximately in line with the top of the grinder handle arc, and a pulling action fairly horizontal across the top of the arc. In contrast, subject 2 looked to be "sitting" down as well as back from the pedestal, and hauling the handles from the top of the arc and down in front of his body. This observation was supported by the kinematic data collected from the video footage. It showed subject 2 to have greater knee and hip flexion, a greater shoulder angle, a lower vertical position for all three position variables (shoulder, hip, and COM), and lower shoulder and COM vector angles than any other grinder operator in the study. Getting in to such a low position meant that the main pull phase was travelling in a much more downward direction than was intended. This was not a problem in itself, but the act of pulling in this manner would probably put the body off balance due to the combined downwards forces of the body weight and gravity. As a result, the opposing hand to the one producing the pull would not only not be aiding the rotation of the handles (which was probably the case in heavy load grinding) but would very likely be impeding it. With the force of the body moving downward during the pull, some of this weight would be transferred to the opposing hand, which would then counteract the upward movement of the opposite handle. This would result in a net decrease of the velocity of rotation, and therefore inhibit the amount of work done. As well as having an overall negative effect on grinding performance, this lower body position also explained the non-uniform kinematic changes exhibited by subject 2. As the main pull phase was now in a more downward direction, as opposed to the more horizontal/flat direction intended, the movement of the body also underwent more vertical movement. This resulted in the increases of shoulder$_y$ and COM$_y$ ranges of movement for subject 2. The decrease in shoulder vector magnitude was due to the difference between the decrease in shoulder$_y$ position (-10 cm) and the increase in shoulder$_x$ position (7 cm). As the vertical distance between the shoulder and the hub decreased more than the horizontal distance had increased, the result was a net decrease in the vector magnitude.

Subject 8 exhibited the greatest number of substantial non-uniform changes, although none of them were divergent enough to be considered statistically significant. Hip angle, ankle-hip angle, COM$_y$ position, shoulder$_y$ position, and COM vector angle all increased where they should have decreased while shoulder angle and hip$_x$ position showed unexpected decreases.

The mechanism for the increases in COM_y position, $shoulder_y$ position, and COM vector angle appear to have been the same as for subject 1. The lack of much change in the hip_y position when combined with a more upright trunk resulted in an increase in $shoulder_y$ position, which resulted in an increase in COM_y position and therefore COM vector angle. This interaction between the lack of vertical hip position change and the decrease in trunk angle also affected the shoulder and hip angles. With the trunk straightening and the shoulder joint rising, a decrease of the angle at the shoulder joint will naturally occur. In contrast, with no great decrease in hip_y position and the trunk straightening the angle at the hip joint will increase. This final effect will be further exaggerated by the forward movement of the hip joint, which is also linked to the increased ankle-hip angle, as the decrease in hip_x position (-4 cm) is greater than the decrease in hip_y position. The reduction in hip_x position was most likely a mechanism to enable the trunk to become more upright and the shoulder joint to move further back whilst still maintaining balance. The end result of this adjustment was that neither the COM_x position nor the hub to shoulder vector/pull angle changed any great deal, however, despite the numerous excursions from what would be considered the "model" response, subject 8 still exhibited a 3.2% increase in performance following the intervention. The apparent positive influences that greater body weight, height and strength have on the effectiveness of kinematic changes in improving performance helps explain why subject 8 showed the 3.2% improvement in performance that he did. While the changes made in his kinematics where generally fairly small, and occasionally in the "wrong" direction, at 201 cm tall, having a predicted 1RM bench pull of 130+, and weighing 119 kg, subject 8 was the tallest, strongest, and second heaviest grinder operator in this study. Subsequently any changes made in kinematics were exaggerated on three fronts, resulting in relatively small kinematic changes producing what would appear to be disproportionately large improvements in performance.