# THE EFFECT OF TWO FORCE SLEDGE APPARATUS JUMPING PROTOCOLS ON TRIAL TO TRIAL RELIABILITY AND MUSCLE PERFORMANCE

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This experiment examined the effect of differing jump protocols performed on a specially constructed force sledge apparatus on trial to trial reliability and overall lower extremity muscular performance. Eight adult volunteers, of varying activity profiles, participated in this study. On the force sledge apparatus, subjects performed bouts of drop jumps and rebound jumps. Measurements of flight time, ground contact time, reactive strength index, peak ground reaction force, displacement of spring mass and vertical stiffness were obtained for three drop jumps and three rebound jumps on the subjects' preferred jumping leg. The results indicated that the rebound jump protocol provided a tighter control of ground contact times and displacement of spring mass, indicating a more consistent jumping strategy. Additionally, a significantly higher peak ground reaction force was produced in the rebound jump protocol.

**KEY WORDS:** drop jump, rebound jump, jump strategy, ground reaction force

**INTRODUCTION:** The force sledge apparatus has been developed to measure external kinetic output of the lower extremities in dynamic exercise and has been used in several studies (Harrison & Gaffney, 2004a; Harrison et al., 2004b, Kryöläinen & Komi, 1995, Nicol et al., 1996). This apparatus can provide quantification of performance measures such as flight time, height of jump and reactive strength index, muscle mechanical properties such as stretch shortening cycle function and leg-spring stiffness, as well as information regarding jumping strategies such as crouch depth and ground contact time. The sledge allows experimenters to isolate the joint action of interest, standardise eccentric loadings and minimise the contribution of extraneous factors such as arm swing and contra-lateral leg action. The sledge has often been used to perform two different jumping protocols: 1) drop jumps, in which subjects are dropped from a fixed height and perform a single maximal one-legged jump upon landing, this utilises a single stretch shortening cycle (Harrison & Gaffney, 2004a; Harrison et al., 2004b) or 2) rebound jumps, in which the subjects are again dropped from a fixed height but perform repeated maximal one-legged jumps upon landing, utilising repeated stretch shortening cycles (Kuitonen et al., 2003). The purpose of this investigation was to establish the trial-to-trial reliability of both protocols on certain biomechanical variables and to examine whether changes in performance are associated with a change in testing procedure.

**METHODS:** Healthy, adult volunteers were recruited for this experiment. Volunteers with a recent serious lower limb injury were excluded from participation. Eight adults, of varying activity profiles, participated in the study, consisting of five males (mean ± S.D.) aged 22 ± 0.5 years; mass 85 ± 8 kg, and three females aged 22 ± 1 year; mass 61 ± 6 kg. The University's research ethics committee approved the study. Informed consent was obtained in writing, from all subjects prior to their participation in the study.

**Procedures:** Measures of lower extremity muscular function were obtained using the force sledge apparatus following two testing protocols. The force sledge consists of a sledge with attached chair sliding on a fixed track inclined at 30° to the horizontal. A winch with a quick pull-release mechanism is located at the top of the track. This can be attached to the sledge and used to hoist subjects to desired heights for dropping. A force plate is positioned at right angles to the base of the track.

In the first protocol, each subject performed drop jumps from a drop height normal to the force plate of 0.30 m along the 30° inclined track. Subjects were first given a visual demonstration and then allowed two practice jumps before performing three jumps on the preferred jumping leg for which data was recorded.

In the second protocol, subjects were again dropped from a height of 0.30 m. Upon landing the subjects performed four repeated maximal jumps. The first jump of this set of four is considered a drop jump; the following three jumps are considered rebound jumps. Again the subjects were first provided with a visual demonstration and then allowed to practice the rebound jumping action twice before performing the protocol on the preferred jumping leg for which data was recorded.

In both protocols subjects were instructed to jump maximally and to minimise their ground contact time. Reflective markers were attached to the sledge and sagittal plane SVHS video recordings (50 Hz.) were obtained. The video recordings were digitised using Peak Motus® (Peak Performance Technologies, Colorado, USA) and the displacement of the sledge was calculated. Ground reaction force measurements were obtained for each jump using an AMTI force plate which sampled at 1000 Hz. Instants of initial foot contact, full crouch depth, take-off and landing were identified using the acquired video footage and ground reaction force traces. Flight time (FT) was calculated as the time between take-off and landing. Contact time (CT) was defined as the time between initial foot contact and take-off. A spring mass model was used to analyse vertical leg spring stiffness. Vertical stiffness of the spring which occurs normal to the force plate, ($K_{VERT}$), was defined as the ratio of the peak force in the spring, $Fy_{peak}$, to the displacement of the spring, $\Delta L$, at the instant the leg spring is maximally compressed. $Fy_{peak}$ and $\Delta L$ both occur simultaneously in the mass spring model (Ferris and Farley, 1997). $\Delta L$ was calculated as the displacement of the sledge from the point of initial foot contact and full crouch depth. Reactive Strength Index was defined as the ability to change quickly from and eccentric to concentric contraction (Young, 1995). In the derivation of RSI an intermediate calculation of jump height was first needed. Considering the 30° inclination of the force sledge apparatus, jump height was approximated as $(9.81 * FT^2)/16$ and RSI was then calculated as the height jumped divided by CT.

**Statistical Analyses:** All statistical analysis of the data was carried out in SPSS © (Release 12.0.1). Trial to trial reliability analysis of recorded variables under each jump protocol utilised the Cronbach's alpha reliability coefficient and intra-class correlations. Reliability coefficients were then analysed for between-protocol differences with paired student t-tests. Comparative analysis, between the drop jump and rebound jump protocols, utilised a general linear model (GLM), ANOVA with repeated measures. The GLM had two within-subjects factors: namely, Jump Protocol (with 2 levels: drop jump protocol or rebound jump protocol and Trial (with 3 levels: Drop Jump No. 1, 2 and 3 or Rebound Jump No. 1, 2 and 3). The dependent variables were FT, CT, RSI, $K_{VERT}$, $Fy_{peak}$ and $\Delta L$. The model included all interaction terms.

**RESULTS AND DISCUSSION:** The effects of jump protocol on trial to trial reliability are shown in Table 1. These data demonstrate that both the drop jump and the rebound jump provide reliable measures of performance (FT, RSI) and muscular mechanical properties ($Fy_{peak}$, $K_{VERT}$) during one-off testing.

While the drop jump protocol provides good reliability of the FT and RSI variables, the data show a high degree of trial to trial variability of the constituents of jumping strategy: CT and $\Delta L$. This variation appears to be reduced with the introduction of the RBJ protocol. The rebound jump protocol provides a tighter control of ground contact times and crouch depth suggesting the protocol elicits a more consistent jumping strategy.

The variability across trials in CT and $\Delta L$ may be explained by subjects implementing differing jumping strategies from trial to trial and attempting to identify a strategy for optimal jump performance. In the sledge-jumping task, the laws of projectile motion govern performance where the subjects themselves become the projectile. The flight time of the projectile or the height of the jump is dependent on the force applied by the subject, the time period it is applied for and the angle of release. Considering the rigid construction of the force sledge apparatus, the release angle is held constant. FT then, becomes dependent on the product of force applied and the time period of force application.

The drop jump task is representative of single explosive jumping effort. With subjects having to be re-hoisted to the appropriate drop height between each trial, there is more time between trials and this perhaps allows for more conscious thought toward selection of jumping strategy. To attain the same performance outcome (i.e. a fixed FT or height of jump) a subject can create varying combinations of force applied ($Fy_{peak}$) and time of force application (CT). In DJ protocol, subjects produce a consistent jumping performance, as evidenced by high FT reliability coefficients, but a less consistent jumping strategy, demonstrated by the low ΔL and CT reliability coefficients.

**Table 1 Trial to trial reliability for all recorded variables. (* indicates significant difference between drop jump and rebound jump protocols, p < .05).**

| | Drop Jumps | | | | Rebound Jumps | | | |
|---|---|---|---|---|---|---|---|---|
| | C.V. (%) | *Reliability α* | ICC *(single)* | *ICC (average)* | C.V. (%) * | *Reliability α* * | *ICC (single)* | *ICC (average)* |
| ***FT*** | 1.9 | .982 | .95 | .983 | 1.9 | .990 | .963 | .987 |
| $Fy_{peak}$ | 6.4 | .971 | .907 | .967 | 5.6 | .991 | .953 | .984 |
| ***CT*** | 9.3 | .717 | .431 | .694 | 5.5 | .971 | .921 | .972 |
| ***RSI*** | 9.8 | .952 | .859 | .948 | 6.1 | .989 | .968 | .989 |
| $K_{VERT}$ | 14.4 | .956 | .863 | .950 | 9.9 | .984 | .943 | .980 |
| ***ΔL*** | 9.2 | .730 | .472 | .728 | 6.4 | .938 | .847 | .943 |

Conversely, the rebound jump protocol is more representative of a maximal repeated hopping task. It demands jumps to be executed in immediate succession and the jumping action becomes cyclical in nature, allowing little or no time for conscious jump strategy selection. This produces a more consistent selection of jumping strategy. This is demonstrated with an increase in Cronbach's alpha reliability co-efficient and a decrease in the coefficient of variance across all measured variables in the RBJ protocol ($p < .05$).
Figure 1 displays performance variables during both types of jumping protocol. It is clear that the RBJ protocol caused significant increases in $Fy_{peak}$ ($p = .006$) and a trend of increased FT ($p = .059$). Increased $Fy_{peak}$ in the RBJ protocol are likely attributed to changes in drop height, which occur following the initial drop jump. In the RBJ protocol, subjects are dropped from a starting height of 0.30 m, following the initial drop jump they enter into the cyclical rebound jump task. Mean jump height in this preceding DJ task was $0.33 \pm 0.08$ m. Subjects were therefore entering the RBJ protocol with a greater drop height than that of the DJ protocol (0.30 m) and with a mean RBJ height of $0.34 \pm 0.07$m this greater drop height was continued throughout the three RBJ trials. Such an increase in drop height would provide a greater eccentric loading of the stretch-shortening cycle and require a larger $Fy_{peak}$ to overcome downward momentum and execute the rebound jumps. Therefore, while the RBJ provides a more consistent jumping strategy than the DJ, there are variances in drop height and there may be variances in eccentric loading from trial to trial. It is recommended that future work utilise the varying drop height during the RBJ protocol as a covariant in statistical analyses for increased validity. It should, however, be noted that a limitation to the present study is the small sample size (n = 8). A larger number of subjects would provide greater general application of the data.
Researchers using sledge protocols should give careful consideration when deciding which protocol to use. The DJ protocol may be more suitable for studies examining maximal, single-leg jumping effort such as the long jump or changes in stretch-shortening cycle function. Evidence suggests that hopping in place, as in the RBJ protocol, follows the same basic mechanics and the spring mass model of running locomotion (Ferris & Farley, 1997) and is more representative of forward running. The RBJ protocol would perhaps then be more appropriate where information regarding effect on running performance is desired.

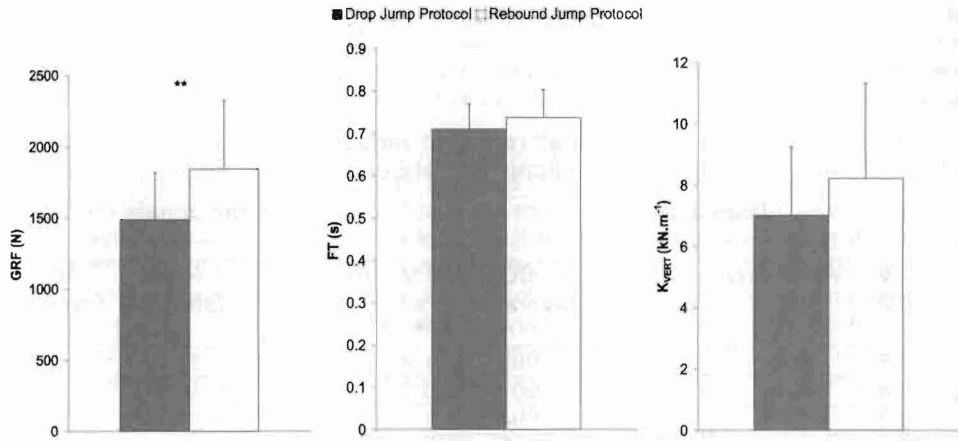


**Figure 1 Mean scores + 95% Confidence Interval (GRF, FT and $K_{VERT}$) during the drop jump and rebound jump protocol. (** indicates significant difference between drop jump and rebound jump, $p < .01$).**

**CONCLUSION:** The results of this experiment indicated that both the drop jump and the rebound jump testing protocols, on the force sledge apparatus, provide reliable measures of performance (FT, RSI) and muscle-mechanical properties ($Fy_{peak}$, $K_{VERT}$) during one-off testing. However, the rebound jump protocol provides a more consistent jumping strategy from trial to trial. This was evidenced by a tighter control of CT and $\Delta L$. $Fy_{peak}$ significantly increased in the RBJ and this was attributed to increases in drop height, which occurred due to the nature of the protocol. As the protocols are representative of two distinct action patterns consideration should be made for the most valid protocol selection.

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