INFLUENCE OF DIFFERENT INERTIAL LOADINGS ON FORCE CHARACTERISTICS DURING SQUAT WITH A FLYWHEEL LOADING DEVICE.

Nobuhisa Yoshida[1], Kimitake Sato[1], Garett Bingham[1], Kevin Carroll[1], John Wagle[1], Nicholas Fiolo[1], Joseph Walters[1], Landon Powell[1], & Michael H. Stone[1].

[1]East Tennessee State University, Department of Exercise and Sport Science, Johnson City, TN, USA

INTRODUCTION: Selection of loading modalities in training is a critical component of program design in an attempt to achieve an optimal training outcome and improved performance. Recently, eccentric overloading has captured more attention as an effective training modality with regard to sports performance and rehabilitation. Previous studies have shown the effectiveness of eccentric overloading to improvements in muscular strength and work capacity (Walker et al., 2016), increased performance in change-of-direction, jumping and sprinting ability (de Hoyo et al., 2014), as well as pain reduction and improvement of functionality of patella and Achilles tendinopathy patients (Romero-Rodriguez, Gual, & Tesch, 2011; Yu, Park, & Lee, 2013). Collectively, previous research suggests that eccentric overloading may be an effective variation of training modality if appropriately sequenced within a periodization strategy focusing on enhanced athletic performance and rehabilitation.

The flywheel inertial resistance may be one of the eccentric-enhancing loading methods. In this loading modality, the resistive force is dynamic, independent of gravity, and the inertial resistance is proportional to the force applied by the user (Chiu & Salem, 2006). The effectiveness of the inertial eccentric overloading with this method has been studied (Fernandez-Gonzalo, Lundberg, Alvarez-Alvarez, & de Paz, 2014; Gual, Fort-Vanmeerhaeghe, Romero-Rodríguez, & Tesch, 2015), and these devices are now used for top athletes' training as well as rehabilitation and injury prevention. However, to the best of authors' knowledge, a limited number of studies are currently available on force characteristics using flywheel inertial resistance device. Therefore, the purpose of this study was to investigate lower extremity force characteristics during a squat with different inertial loadings of the flywheel training device.

METHODS: Ten recreationally trained healthy participants (9 male & 1 female, weight = 87.43 ± 17.42kg) participated in this investigation. All participants performed the squat on kBox flywheel training machine (Exxentric AB, Sweden) using a harness attached to a suspension band causing the flywheel to rotate. While performing squats with this machine, the participants accelerated and decelerated the flywheel in order to create inertial concentric and eccentric loadings. This study was reviewed and approved by the East Tennessee State University Institutional Review Board.

Testing protocol: All participants performed one familiarization session using the same protocol as that of the testing session at least one week prior to the data collection, in order to avoid the confounding effects of muscle fatigue and delayed onset of muscle soreness. After performing self-selected warm-ups, two sets of 13 repetitions squats, where the first 3 were included to cause momentum, with three different inertial flywheels (light:0.010 kgm^2, medium:0.025 kgm^2, and heavy:0.050 kgm^2) were performed on portable dual force plates (0.36 m x 0.36 m, PASCO Scientific PS-2142, Roseville, CA) on the top of the device. Each foot was placed in the center of the each force plate with fixed toe angle for consistency (Sato & Heise, 2012). The participants completed their first 2 sets with the smallest inertial flywheel (0.010 kgm^2), and then progressively increased the loading with 0.025 kgm^2 and 0.050 kgm^2, respectively. The participants were given a rest period of 2 minutes between the same flywheel, and 3 minutes between the different ones. All participants wore the same model of shoes (Supernova, Adidas, Germany) in order to minimize confounding effects from different footwear.

Data Collection: Vertical ground reaction forces (vGRF) during squats were collected using the dual force plates sampling at 500 Hz. with Capstone software (Pasco, Roseville, CA, USA). Data processing was performed using self-costumed program with Excel 2016 spreadsheet (Microsoft Corp. Redmond, WA) to obtain Peak force [PF], Net Impulse [NI], and a positive to negative impulse ratio [P:N-IMP] for each inertial loading.

Statistical Analysis: Descriptive statistics including group mean, standard deviation (SD), and coefficient of variance (CV), were calculated. Pairwise t test was used to assess consistency of the data for intra-session reliability of the squats with the same flywheel. To determine statistically significant differences between the levels of inertial loading in PF, NI, P:N-IMP, three separate repeated measures of ANOVA with Tukey's post hoc test was conducted. Normality of the data, equality of variance, assumption of sphericity were assessed by Shapiro-Wilk test, Leven's test, and Mauchly's test, respectively. For practical significance, Cohen's d effect sizes (d) was calculated, and d < 0.2, 0.2-0.6, 0.6-1.2, 1.2-2, and 2.0-4.0 were considered as trivial, small, moderate, large and very large, respectively (Hopkins, Marshall, Batterham, & Hanin, 2009). All statistical analyses were performed using SPSS 23 (IBM, New York, NY), and effect size calculations were performed using analysis package in R Studio (Boston, MA USA). Significance was set at $\alpha = 0.05$.

RESULTS: Ensemble mean, standard deviation (SD), and coefficient of variation (CV) are presented in Table 1. For reliability of the data for each resistance, light flywheel (0.010 kgm^2) demonstrated small magnitude of inconsistency between set 1 and set 2 in all three variables, PF_{light}, t(9) = 3.77, *p* =.004, d = 0.35; NI_{light}, t(9) = 2.67, *p* =.026, d = 0.48; N:P-IMP_{light}, t(9) = 2.96, *p* =.016, d = 0.30. In comparison of mean value, the assumption of normality had been violated for all Independent variables, therefore Greenhouse-Geisser corrected tests are reported. The results show that statistically significant differences between three different flywheel resistance existed for the all force variables, PF; $F(1.39, 26.47) = 23.43$, $p > 0.001$, $\omega^2 = 0.13$; NI; $F(1.17, 22.27) = 191.90$, $p > 0.001$, $\omega^2 = 0.83$; P:N-IMP; $F(1.03, 19.49) = 42.04$, $p > 0.001$, $\omega^2 = 0.58$ (table 2).

DISCUSSION: The purpose of this study was to investigate the force characteristics changes with different inertial resistance during the squat. Findings demonstrated clear differences between different inertial resistance in all force variables, PF, NI, and P:N-IMP, except PF_{medium} vs PF_{heavy}. The greater PF produced greater inertial eccentric loading which resulted in greater NI and P:N-IMP. Increase in NI and P:N-IMP indicates the relatively greater increase in positive impulse than negative impulse. The unique finding of this study was that, with this loading method, relatively small increase in PF (d = 0.58 & 0.81) resulted in substantial increase in NI (d = 3.44, 4.31, and 2.06) and P:N-IMP (d = 2.37, 2.08, and 1.49). This result may indicate that flywheel inertial resistance may be useful method to produce eccentric overloading with relatively small increase in amount of force production.

In addition, in peak force, there was no significant difference between PF_{medium} and $PF_{heavy,}$ and the relatively greater CV in PF_{heavy} has been shown in this study. This result may indicate the difference in strength level among the participants. In nature of the flywheel inertial resistance, the applied force accelerates the inertial torque which produce resistive force during descending phase of squat (Chiu & Salem, 2006). Therefore, the greater variance in PF could have resulted in corresponding greater CV in N:P-IMP_{heavy}. It is assumed that the relatively weak participants were unable to overcome the inertial load to create a greater eccentric overload stimulus. This may imply the lifters strength capability could differentiate the overall impulse, especially the eccentric impulse, and potentially affect the overall training outcome.

Lastly, the small magnitude of inconsistency of the data between set 1 and set 2 of light resistance could be due to the warm-up effects in both kinetic and kinematic variables, and/or it might be difficult for participants to produce consistent force with light resistance.

To conclude, flywheel inertial resistance produces eccentric overloading with greater NI and P:N-IMP, with relatively small increase in PF using individually-suited flywheel inertial resistance. This training modality may be beneficial to enhance sports performance, especially for athletes who possess high level of strength capability. Based on these findings, further investigation in future studies should look into a more detailed analysis of eccentric and concentric phase specific variables, as well as the comparison of the force data with different type of loading modalities, such as free weight resistance and velocity-based loading.

REFERENCES

Chiu, L. Z., & Salem, G. J. (2006). Comparison of joint kinetics during free weight and flywheel resistance exercise. *The Journal of Strength & Conditioning Research, 20*(3), 555-562.

de Hoyo, M., de la Torre, A., Pradas, F., Sañudo, B., Carrasco, L., Mateo-Cortes, J., . . . Gonzalo-Skok, O. (2014). Effects of Eccentric Overload Bout on Change of Direction and Performance in Soccer Players. *International journal of sports medicine, 36*(04), 308-314. doi:10.1055/s-0034-1395521

Fernandez-Gonzalo, R., Lundberg, T. R., Alvarez-Alvarez, L., & de Paz, J. A. (2014). Muscle damage responses and adaptations to eccentric-overload resistance exercise in men and women. *Eur J Appl Physiol, 114*(5), 1075-1084. doi:10.1007/s00421-014-2836-7

Gual, G., Fort-Vanmeerhaeghe, A., Romero-Rodríguez, D., & Tesch, P. A. (2015). Effects of in-season inertial resistance training with eccentric overload in a sports population at risk for patellar tendinopathy. *Journal of strength and conditioning research/National Strength & Conditioning Association*.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc, 41*(1), 3-13. doi:10.1249/MSS.0b013e31818cb278

Romero-Rodriguez, D., Gual, G., & Tesch, P. A. (2011). Efficacy of an inertial resistance training paradigm in the treatment of patellar tendinopathy in athletes: a case-series study. *Phys Ther Sport, 12*(1), 43-48. doi:10.1016/j.ptsp.2010.10.003

Sato, K., & Heise, G. D. (2012). Influence of weight distribution asymmetry on the biomechanics of a barbell back squat. *The Journal of Strength & Conditioning Research, 26*(2), 342-349.

Walker, S., Blazevich, A. J., Haff, G. G., Tufano, J. J., Newton, R. U., & Hakkinen, K. (2016). Greater Strength Gains after Training with Accentuated Eccentric than Traditional

Isoinertial Loads in Already Strength-Trained Men. *Front Physiol, 7*, 149. doi:10.3389/fphys.2016.00149

Yu, J., Park, D., & Lee, G. (2013). Effect of eccentric strengthening on pain, muscle strength, endurance, and functional fitness factors in male patients with achilles tendinopathy. *American journal of physical medicine & rehabilitation, 92*(1), 68-76.

Table 1. Descriptive Statistics in Measured Variables with Different Inertial Resistances.

Testing variable		light 0.010 kgm^2	medium 0.025 kgm^2	heavy 0.050 kgm^2
PF (N)	Mean	1635.8 *	1860.1	1993.1
	SD	356.3	415.8	509.7
	CV	0.22	0.22	0.26
NI (Ns)	Mean	275 *	616.4	970.5
	SD	79.8	115.5	213.5
	CV	0.29	0.19	0.22
P:N-IMP (AU)	Mean	3.93 *	9.42	24.14
	SD	1.45	2.93	13.67
	CV	0.37	0.31	0.57

PF, peak force; **NI**, net impulse; **P:N-IMP**, positive to negative impulse ratio; **SD**, standard deviation; **CV**; coefficient of variation, **AU**, arbitrary units.

* Significant differences (inconsistency) with small-sized effect between set1 & set2

Table 2. Pairwise comparison in PF, NI, and P:N-IMP between three resistance

Variables	Comparison			*p*	Effect Size (d)
PF	PF_{light}	vs	PF_{medium}	< 0.001*	0.58
	PF_{light}	vs	PF_{heavy}	< 0.001*	0.81
	PF_{medium}	vs	PF_{heavy}	0.060	0.29

NI	NI_{light}	vs	NI_{medium}	< 0.001*	3.44
	NI_{light}	vs	NI_{heavy}	< 0.001*	4.31
	NI_{medium}	vs	NI_{heavy}	< 0.001*	2.06
P:N-IMP	$P{:}N\text{-}IMP_{light}$	vs	$P{:}N\text{-}IMP_{medium}$	< 0.001*	2.37
	$P{:}N\text{-}IMP_{light}$	vs	$P{:}N\text{-}IMP_{heavy}$	< 0.001*	2.08
	$P{:}N\text{-}IMP_{medium}$	vs	$P{:}N\text{-}IMP_{heavy}$	< 0.001*	1.49

PF, peak force; **NI**, net impulse; **P:N-IMP**, positive to negative impulse ratio; **SD**, standard deviation;
d, Cohens' d effect size

* Statistaically significant difference