SQUATS PERFORMED ON AN UNSTABLE SURFACE ELICIT HIGHER TRANSVERSAL FORCE OUTPUT COMPARED TO MORE STABLE SQUATS

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Instability resistance training (RT) or exercising within an unstable environment is a popular training modality and frequently used in training, rehabilitation and prevention settings. Yet, due to the reported reduced force output during exercising within unstable condition, instability RT is said to lack the necessary overload to induce meaningful effects. However, empirical evidence of interventions suggests otherwise. The aim of this study was to systematically analyse instability RT vs. stable RT and discuss potential mechanisms. Therefore, we analysed squats within more unstable and more stable environments and calculated transversal and vertical forces. Greater transversal plane ground reaction forces were observed while performing squats on the more unstable surface ($p \leq .001$; $d = 3.70$, $BF_{10} = 53213.49$). In contrast, vertical force output remained similar for both conditions ($p = .058$; $d = 1.14$, $BF_{10} = 1.36$).

KEYWORDS: instability, unstable, metastable, resistance training, squat.

INTRODUCTION: There is an ongoing and lengthy discussion going on regarding the relevance and effectivity of resistance training (RT) performed within unstable conditions (Behm & Colado, 2012; Behm & Colado Sanchez, 2013; Behm, Drinkwater, Willardson, & Cowley, 2010), the role of functional training for activities of daily living (La Scala Teixeira, Evangelista, Novaes, Silva-Grigoletto, & Behm, 2017) and the adaptive specificity of resistance training (Behm & Sale, 1993; Buckthorpe, Erskine, Fletcher, & Folland, 2015; Contreras et al., 2017; Rutherford & Jones, 1986; Sale, 1988). Unfortunately, we find a wide range of different methods in research investigating RT performed within unstable conditions and the discussion of potential effects of this modality seems rather black-and-white. Thus, the aim of this investigation is the beginning to systematically analyse RT performed within unstable conditions and discuss the results in the appropriate context.
The main argumentation of rejecting RT performed within unstable conditions comes from an abundance of literature demonstrating meaningful reduction in force and power, compared to more stable RT (Behm & Colado, 2012; Willardson, 2004). These results are not unexpected. Due to the necessity to stabilise the centre of mass (CoM), athletes/patients exercising within an unstable environment need to reduce the load, although the intensity (i.e. 80 % of the 1RM) remains the same in the stable and unstable condition. Based on the potentially missing overload, RT performed within unstable conditions is said to be not suitable for high performance sports and hypertrophy training (Willardson, 2004). There are a couple of critical issues being overlooked here. Firstly, hypertrophy may not be the primary goal of RT performed within unstable conditions. A recent investigation showed that the effects of free weight RT on unstable surfaces lay more within multisegmental coordination than maximal strength gains (Eckardt & Rosenblatt, 2019). Secondly, given that the methods of previous investigations lack transparency, it may well be that higher vertical force output is only due to the increased load within more stable conditions. Lastly, ground reaction forces (GRF) in the transversal plane (ML and AP) have been ignored. However, those forces could be an indicator of the total amount of work, a specific stimulus provided to the neuromuscular system and why RT performed within unstable conditions affects multisegmental coordination. All in all, there is a need for a systematic approach to investigate RT performed within unstable conditions to fill missing gaps in the literature.

Therefore, we compared vertical and transversal GRF during squats under stable and unstable conditions, while keeping the load and the TuT constant. We hypothesised first, that the vertical GRF would not differ between conditions. Secondly, we assume that GRF in the transversal plane would be larger within the unstable condition, compared to the stable condition.

METHODS: Sixteen (eight females, eight males) sport science students participated in this study (M_{AGE} = 22.9, SD_{AGE} = 1.9; M_{WEIGHT} = 69.6 kg, SD_{WEIGHT} = 11.9 kg; M_{HEIGHT} = 176.2 cm, SD_{HEIGHT} = 10.5 cm). Selection criteria were minimal prior experience with resistance training and squats in particular (knowledge about the movement pattern). All participants provided written informed consent prior to data collection.

After a familiarisation phase to get accustomed to performing squats with one kettle bell in each hand (total of 33% of bw) during a stable and an unstable condition (Togo Balance Trainer Jumper, Prien-Bacham, Germany) and following a computerized metronome (Büsch [2013]. Strength Training Clock 6.0, IAT Leipzig, Germany) to control for TuT (2 s Eccentric, 2.5 s Concentric and 1 sec standing), participants performed two sets of 10 repetitions each (40 reps in total). A minimum of at least two min rest was provided to avoid fatigue. The condition of the first set was randomised and then alternately carried out. Squat stance was individually based on the distance of the left and right anterior superior iliac spine.

We used a twelve-camera motion capture system (Vicon, Oxford, UK) operating at 200 Hz to track the motion of 26 super-spherical markers placed bilaterally at prominent landmarks according to a modified IOR-model (Leardini, Biagi, Merlo, Belvedere, & Benedetti, 2011; Leardini et al., 2007). GRF were obtained using a 400x600mm AMTI force plate (BP400600) operating at 1000 Hz. Nexus 2.9.3 was used to record kinematic and dynamic data and to reconstruct marker trajectories. Kinematic trajectories were then labelled in QTM (Qualisys AB, Gothenburg, Sweden) and were processed using Visual3D (C-Motion, Germantown, MD, USA). Raw kinematic marker trajectories were interpolated and smoothed with a fourth-order zero-lag Butterworth low-pass filter with a cut-off frequency of 6 Hz, while analogue data was filtered with 50 Hz. We used changes in knee angles to determine eccentric and concentric phases of the squat. GRF were normalised to bodyweight and load. The ML and AP component of the GRF was then rectified and we calculated the area under the curve (AUC) for transversal (ML and AP) and vertical GRF.

Prior to the main statistical analysis, normal distribution was checked by visual inspection and tested with the Shapiro-Wilk test for each dependent variable. To test our hypotheses, we conducted paired t-tests (or the non-parametric alternative Wilcoxon test, respectively) to investigate differences between conditions. Further, we employed Bayesian t-tests and calculated Bayes Factors (BF) to extend explanatory power of the inference t-tests results. We assume a default Cauchy prior width of 0.707. In addition, we calculated effect sizes (Cohen’s d). Following Cohen (1988), d-values ≤ 0.49 indicate small effects, 0.50 ≤ *d* ≤ 0.79 indicate medium effects, and *d* ≥ 0.80 indicate large effects. Alpha level was set at 5%. All tests were computed using JASP (Version 0.11.1).

RESULTS: Given the violation of normal distribution for stable transversal, we used non-parametric statistics. It seems, that there is a large effect in the transversal plane ($p \leq .001$; $d = 3.70$,) and extreme evidence (BF_{10} = 53213.49) for a difference between conditions, with increased GRF for the unstable condition compared to the stable condition. Vertical GRF does not differ ($p = .058$; $d = 1.14$,) and only anecdotal evidence for a difference (BF_{10} = 1.36) can be found.

Table 1: Descriptive statistics.

N/BW+load	Stable Transversal	Unstable Transversal	Stable Vertical	Unstable Vertical
Mean	0.76	1.53	53.51	52.56
Std. Deviation	0.13	0.38	0.70	1.71
Minimum	0.61	1.13	52.23	49.40
Maximum	1.13	2.55	55.03	56.67

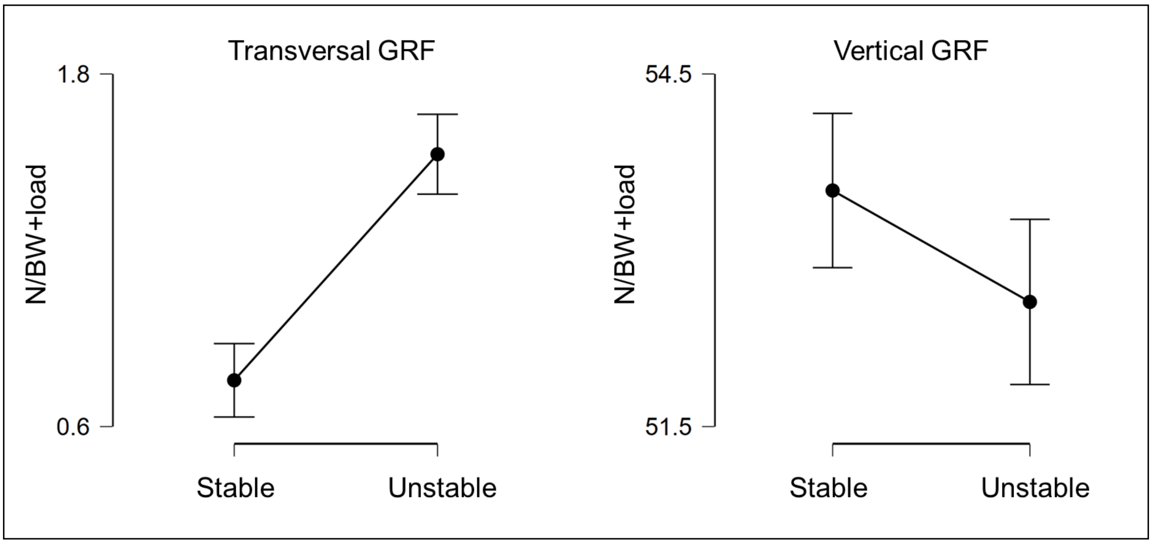

Figure 1: Mean transversal and vertical GRF. Whisker show the 95%-CI.

DISCUSSION: This is the first investigation to our knowledge to examine differences in GRF output in the transversal plane and vertical direction under stable vs. unstable conditions, while load and TuT is kept constant. The purpose of the study was to systematically investigate the GRF output in stable vs. unstable RT. Our first hypothesis, that vertical GRF would not differ between conditions can be supported. Regarding our second hypothesis, that the unstable condition elicits increased GRF in the transversal plane, was also supported.

The results were somewhat expected, in particular for the vertical GRF, given that load was identical for both conditions. This is in contrast to almost every other investigation comparing stable vs. unstable conditions, reporting decreased force output (Behm & Colado, 2012). Looking closely at those reports, it is striking that in most cases the maximum voluntary contraction force (Behm, Anderson, & Curnew, 2002; McBride, Cormie, & Deane, 2006) or isometric peak force (McBride et al., 2006) was measured. However, Goodmann and colleagues (Goodman, Pearce, Nicholes, Gatt, & Fairweather, 2008) found no difference in dynamic 1 RM strength and muscle activation when comparing barbell chest press on a stable and unstable surface. Interestingly, the duration of the 1RM lift did not differ either. In a study by (Cowley, Swensen, & Sforzo, 2007), participants exercised for three weeks either a barbell chest press on a stable and unstable surface. Pre- and post-testing revealed only marginal differences between condition between 0.7 % and 2.0 % in the 1 RM. It seems, that the decisive factor, whether vertical force output is decreased or not within unstable conditions is the contraction modality dynamic vs. static. Again, the increased GRF in the transversal plane for RT performed within unstable conditions is not unexpected either, given the fact that within a challenging environment and an multijoint segmental body, the CNS employs strategies to counteract forces that would lead to a loss of postural stability. Within such a challenging unstable condition a constant alternation of postural adjustments would clearly result in an increase of lower extremity and trunk muscle activation. Although, we can find conflicting results on muscle activation, the majority of studies found increased limb and trunk muscle activity during RT performed within unstable conditions (Behm & Colado, 2012). Related research on the effect of RT performed within unstable conditions found enhanced ability to control counter-rotation mechanisms for postural control (Silva, Mrachacz-Kersting, Oliveira, & Kersting, 2018) and lower extremity covariation to stabilise postural control, particular in more challenging walking conditions (Eckardt & Rosenblatt, 2019). The last study in particular demonstrates, that effects of RT performed on unstable surfaces may not be detected by traditional measures like vertical GRF or peak rate of force development, but non-specific measures focusing on covariation rather than maximal force / strength. Yet, this needs further investigation and verification.

CONCLUSION: This study is a first step to systematically investigate the characteristic and potential mechanisms of RT performed within unstable conditions. As previous research has shown, RT performed within unstable conditions is a valid supplementary training modality in addition to power and hypertrophy training or in preventive and rehabilitative situations. The instability-induced increase in transversal GRF and increases in trunk and lower limb muscle activation promotes multijoint coordination, better anticipatory adjustment and counter-rotation mechanisms to maintain postural stability. All these factors may be able to provide greater stabilising functions to protect muscles and articulations and may even increase performance. Coaches and physical therapist should consider a progressive adaption phase with moderate loads and a moderate degree of instability in the beginning; however there is no or weak empirical evidence when RT performed within unstable conditions should be placed within a training cycle, thus we cannot give a honest recommendation in which phase of the training postural challenging conditions should be applied, whether a progressive increase of load and challenge or sudden block changes are better or if stable and unstable RT should be conducted parallel or sequential in within the training cycle. More systematic and thorough research is needed.

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