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Velocity-based training: Monitoring, implementation and effects on strength and power

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**VELOCITY-BASED TRAINING: MONITORING,
IMPLEMENTATION AND EFFECTS ON
STRENGTH AND POWER**

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2019

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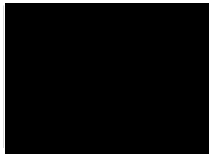
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ありがとうございました (Google Translate, 2018)

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extremely supportive and encouraging. Finally, you can stop saying, “get it done son”. It’s done.

ABSTRACT

Traditionally, resistance training has been prescribed using percent-based training (PBT) methods that use the loads relative to a maximal load lifted for one repetition (1RM). However, PBT does not take into account possible day-to-day fluctuations in performance that may occur from physical or psychological stressors. One approach to address this limitation is to monitor velocity changes during resistance training, based on research showing that declines in velocity are highly correlated with fatigue. Therefore, velocity-based training (VBT) methods are proposed to provide a more objective method to modify resistance training sessions based on individual differences in day-to-day performance and the rate of training adaptation. However, at the commencement of this dissertation in 2014, no previous research had examined VBT methods in comparison to PBT methods. Thus, this thesis aimed to verify the efficacy of different VBT methods using a resistance-trained population who could lift a minimum of 150% their own body mass for at least one repetition in the full-depth back squat. These parameters were chosen so that the findings of this research were applicable to strength-trained athletes who were likely to employ VBT methods in their resistance training programs.

In the first of five research studies, two portable VBT devices were examined for their accuracy to assess peak velocity (PV) and mean velocity (MV) among other kinematic variables. On three separate days, ten strength-trained men performed three 1RM back squat trials that comprised loads of 20%, 40%, 60%, 80%, 90% and 100% of 1RM. Acceptable validity criteria was based on a Pearson moment correlation coefficient >0.70 , coefficient of variation (CV) $\leq 10\%$ and Cohen d effect size (ES) <0.60 . The results showed that the inertial sensor device (PUSH™) was not highly accurate according to the validity criteria for determining PV or MV across all six relative intensities examined. However, a linear transducer ([LT] GymAware™) was highly accurate for measuring both PV ($r = 0.94 - 0.97$, CV = 2.9 – 5.8%) and MV ($r = 0.95 - 0.99$, CV = 3.2 – 4.5%) across the relative load spectrum when compared to laboratory testing equipment. Thus, for the remainder of the VBT studies in this PhD thesis project, an LT was used to report the velocity data.

In the second study, a novel velocity-based load monitoring method was investigated using 17 strength-trained men who performed three 1RM trials on separate days. Specifically, the reliability and validity of the load-velocity relationship to predict the back squat 1RM was calculated by entering MV at 100% 1RM into individualised linear regression equations which were derived from the load-velocity relationship of three (20%, 40%, 60% of 1RM), four (20%, 40%, 60%, 80% 1RM), or five (20%, 40%, 60%, 80%, 90% 1RM) incremental warm-up sets. The

results showed that this predicted 1RM method was moderately reliable ($ICC = 0.72 - 0.92$, $CV = 7.4 - 12.8\%$), and moderately valid ($r = 0.78 - 0.93$, $CV = 5.7 - 12.2\%$). However, it could not be used as a VBT method to accurately modify training loads, since it significantly over-predicted the actual 1RM ($SEE = 10.6 - 17.2$ kg) due to the large variability of MV at 100% 1RM ($ICC = 0.42$, $SEM = 0.05$ m·s⁻¹, $CV = 22.5\%$). Therefore, this 1RM prediction method was no longer utilised as a method of adjusting training load for the remainder of the project.

Despite its suggested importance, research had yet to investigate if velocity was stable between training sessions, so that individualised load-velocity profiles (LVP) could be created to track changes in velocity. Thus, the third study attempted to fill this research gap, where 18 strength-trained men performed three 1RM trials, which included warm-up loads pertaining to 20%, 40%, 60%, 80%, 90% and 100% 1RM, with the velocity of each repetition assessed by LT. It was found that PV, mean propulsive velocity (MPV) and MV were all reliable ($ICC > 0.70$, $CV \leq 10\%$, $ES < 0.6$) for the back squat performed at 20%, 40%, 60%, 80%, and 90% 1RM but not at 100% 1RM for MPV and MV. This meant that all three concentric velocity types could be used to develop LVPs. In addition, the smallest detectable difference was established across the relative load spectrum for PV (0.11 – 0.19 m·s⁻¹), MPV (0.08 – 0.11 m·s⁻¹) and MV (0.06 – 0.11 m·s⁻¹), which then allows coaches to determine meaningful changes in velocity from their athletes between training sessions. Collectively, these results showed that LVPs could be utilised as a VBT method for monitoring sessional changes in velocity and modifying resistance-training loads according to individual differences in day-to-day performance.

The fourth study compared the kinetic and kinematic data from three different VBT sessions and a PBT session in order to provide programmatic guidance to strength coaches who may choose to implement these novel methods to adjust resistance training load or volume. Fifteen strength-trained men performed four randomised resistance-training sessions 96 hours apart, which included a PBT session involving five sets of five repetitions at 80% 1RM, a LVP session (verified from Study 3) consisting of five sets of five repetitions with a load that could be adjusted to achieve a target velocity from an individualised LVP regression equation at 80% 1RM, a fixed sets 20% velocity loss threshold FS_{VL20} session that contained five sets at 80% of 1RM but sets were terminated once MV dropped below 20% of the maximal attainable MV from the first set or when five repetitions were completed, a variable sets 20% velocity loss threshold VS_{VL20} session that comprised 25 repetitions in total but participants performed as many repetitions in a set until the 20% velocity loss threshold was exceeded or 25 repetitions was completed. During the LVP and FS_{VL20} sessions, individuals performed repetitions with faster ($p < 0.05$) sessional MV ($ES = 0.81$

– 1.05) and PV (ES = 0.98 – 1.12), avoided additional mechanical stress with less time under tension but maintained similar force and power outputs when compared to the PBT session. Therefore, the LVP and FS_{VL20} methods could be employed in a strength-oriented training phase to diminish fatigue-induced decreases in movement velocity that can occur in PBT.

The VBT method employed in the fifth and final study was derived from the results of Study 4. Both the LVP and FS_{VL20} methods permitted faster repetition velocities throughout a training session compared to PBT, but it was decided that the FS_{VL20} method could decrease total training volume and reduce the training stimulus, which may be unwarranted. Therefore, in Study 5, the effects of the LVP-VBT approach (VBT) versus PBT on changes in strength, power and sports performance measures following six weeks of back squat training were examined. The study involved 24 strength-trained men who performed back squat training three times per week in a daily undulating format. The training protocols were matched for sets and repetitions but differed in the assigned training load. PBT group trained with relative loads varying from 59% – 85% 1RM, whereas the VBT group trained with loads that could be adjusted to achieve a target velocity from an individualised LVP that corresponded with 59% – 85% 1RM. Pre- and post-training assessments included 1RM, 30% of 1RM countermovement jump (CMJ), 20-m sprint, and 505 change of direction test (COD). Overall, the VBT group performed repetitions with faster velocities during training ($p < 0.05$, MV = 0.76 m·s⁻¹ vs. 0.66 m·s⁻¹) that were perceived as less difficult ($p < 0.05$, rating of perceived exertion = 5.1 vs. 6.0), and utilized marginally lower training loads ($p < 0.05$, ~1.7% 1RM) compared to PBT. Both VBT and PBT methods were effective for significantly enhancing 1RM (VBT: 11.3% vs. PBT: 12.5%), CMJ peak power (VBT: 7.4% vs. PBT: 6.0%), 20-m sprint (VBT: -1.9% vs. PBT: -0.9%), and COD (VBT: -5.4% vs. PBT: -3.6%). No significant differences were observed between groups for any testing assessment but *likely* favourable training effects were observed in 1RM for PBT group, whilst VBT group had *likely* favourable improvements in 5-m sprint time, and *possibly* favourable improvements in 10-m sprint time, and COD time. These findings suggest that both VBT and PBT methods are similarly effective; however, PBT may provide a slight 1RM strength advantage whilst VBT may be preferred by some individuals, since it permits faster training velocities, is perceived as less difficult, and is a more objective method for adjusting training load to account for individual differences in the rate of training adaptation.

In conclusion, VBT (LVP approach) and PBT are similarly effective for promoting significant improvements in strength, power and sports performance tasks in strength-trained participants. However, even though the LVP-based VBT method did not provide significant

increases in strength and power adaptations compared to PBT, it provided similar improvements while avoiding additional mechanical loading which may be important for the better management of training load, particularly with athletes who partake in numerous training modalities which can influence fatigue and recovery. That being said, if all repetitions are performed with maximal intended velocity but not to concentric muscular failure, a well planned, periodized resistance training program with regular training frequency and progressive overload that accounts for bouts of recovery will provide adequate stimulus to significantly enhance strength, power and performance tasks like sprinting and changes in direction. Future training studies may look to examine the efficacy of VBT methods using multiple exercises (upper and lower body), and with different populations including women, adolescents, older adults, and potentially individuals during rehabilitation from injury so that training progress can be objectively monitored. Furthermore, future studies could look to incorporate multiple VBT methods into a training program such as the LVP method to modify resistance training load and the velocity loss thresholds method to control resistance training volume.

TABLE OF CONTENTS

USE OF THESIS	i
DECLARATION	ii
ACKNOWLEDGEMENTS.....	iii
ABSTRACT.....	vi
TABLE OF CONTENTS	x
LIST OF TABLES.....	xv
LIST OF FIGURES.....	xvi
ABBREVIATED TERMINOLOGY.....	xxi
LIST OF PUBLICATIONS AND PRESENTATIONS	xxii
PUBLICATIONS FORMING PART OF THIS THESIS.....	xxii
SCIENTIFIC CONFERENCE PRESENTATIONS RELATED TO THIS THESIS	xxiii
ADDITIONAL PUBLICATIONS RELEVANT TO, BUT NOT FORMING PART OF THIS THESIS	xxiv
CHAPTER 1	1
INTRODUCTION	1
CENTRAL AIM.....	4
CENTRAL HYPOTHESIS.....	4
THESIS OVERVIEW.....	6
CHAPTER 2	7
REVIEW OF THE LITERATURE	7
CHAPTER OVERVIEW	7
INTRODUCTION.....	7
DEVICES MEASURING VELOCITY	9
Motion Analysis.....	9
Linear Transducer (LT) Devices.....	11
Accelerometer-based Devices.....	12
VELOCITY-BASED 1RM PREDICTIONS	14
1RM – Velocity at 100% 1RM ($1RM_{V1RM}$) Prediction Method	14
1RM – Minimum Velocity Threshold ($1RM_{MVT}$) Prediction Method.....	15

1RM – Load at Zero Velocity ($1RM_{LD0}$) Prediction Method	16
1RM – FV and LV Relationships ($1RM_{FV}$) Prediction Method	18
1RM – Body weight 1RM ($1RM_{BW}$) prediction method.....	19
RELIABILITY OF DIFFERENT VELOCITY MEASURES.....	19
LOAD-VELOCITY PROFILES (LVP)	20
VELOCITY LOSS THRESHOLDS.....	22
SUMMARY OF LITERATURE REVIEW	24
CHAPTER 3: STUDY 1.....	25
VALIDITY OF VARIOUS METHODS FOR DETERMINING VELOCITY, FORCE AND POWER IN THE BACK SQUAT	25
ABSTRACT	25
INTRODUCTION.....	26
METHODS.....	27
Participants	27
Study Design.....	27
Testing Procedure	27
One-Repetition Maximum (1RM) Assessment.....	27
Data Acquisition	28
Statistical Analyses	29
RESULTS.....	30
DISCUSSION.....	32
CONCLUSIONS	41
PRACTICAL APPLICATIONS.....	41
CHAPTER 4: STUDY2	42
RELIABILITY AND VALIDITY OF THE LOAD-VELOCITY RELATIONSHIP TO PREDICT THE 1RM BACK SQUAT	42
ABSTRACT	42
INTRODUCTION.....	43
METHODS.....	45
Experimental Design.....	45
Participants	45
Experimental Procedure	46
One-Repetition Maximum (1RM) Assessment.....	46
Data Acquisition	47

Statistical Analyses	48
RESULTS.....	49
Reliability	49
Validity.....	49
DISCUSSION.....	50
CONCLUSIONS	55
PRACTICAL APPLICATIONS.....	56
CHAPTER 5: STUDY 3.....	57
THE RELIABILITY OF INDIVIDUALISED LOAD-VELOCITY PROFILES	57
ABSTRACT	57
INTRODUCTION.....	58
METHODS.....	60
Participants	60
Experimental Design.....	60
Experimental Procedure	60
Data Acquisition	61
Statistical Analyses	62
RESULTS.....	62
DISCUSSION.....	64
CONCLUSIONS	70
PRACTICAL APPLICATIONS.....	70
CHAPTER 6: STUDY 4.....	71
COMPARISON OF VELOCITY-BASED AND TRADITIONAL 1RM-PERCENT-	
BASED PRESCRIPTION ON ACUTE KINETIC AND KINEMATIC VARIABLES .	71
ABSTRACT	71
INTRODUCTION.....	72
METHODS.....	74
Participants	74
Experimental Design.....	74
Experimental Procedure	75
Session One: One-Repetition Maximum (1RM) Assessment.....	75
Session Two: Load-Velocity Profile (LVP) Assessment.....	76
Sessions Three, Four, Five, and Six: Experimental Sessions.....	76
Data Acquisition	77
Statistical Analyses	78

RESULTS.....	79
DISCUSSION.....	79
CONCLUSIONS.....	86
PRACTICAL APPLICATIONS.....	87
CHAPTER 7: STUDY 5.....	88
THE EFFECTS ON STRENGTH AND POWER ADAPTATIONS FOLLOWING SIX WEEKS OF VELOCITY-BASED TRAINING OR 1RM-PERCENT-BASED TRAINING	88
ABSTRACT	88
INTRODUCTION.....	89
METHODS.....	90
Participants	90
Experimental Design.....	91
Experimental Procedure	92
Familiarisation Session	92
One-Repetition Maximum (1RM) Assessment.....	92
Load-Velocity Profile (LVP) Assessment.....	93
Power and Speed Testing Session.....	94
Loaded Countermovement Jump (CMJ)	94
20m Sprint.....	95
505 Change of Direction Test (COD)	95
Training Protocols.....	95
Rating of Perceived Exertion (RPE) Measures.....	96
Statistical Analyses	97
RESULTS.....	97
Training Results.....	97
Testing Results.....	99
DISCUSSION.....	101
CHAPTER 8	107
GENERAL SUMMARY AND CONCLUSIONS.....	107
GENERAL SUMMARY	107
LIMITATIONS.....	110
DIRECTIONS FOR FURTHER RESEARCH	112
REFERENCES	113

APPENDIX A: UNIVERSITY ETHICS COMMITTEE APPROVAL LETTER.....	123
APPENDIX B: INFORMATION LETTER – CHAPTER 3, 4, AND 5: STUDY 1, 2, 3.....	124
APPENDIX C: INFORMATION LETTER – CHAPTER 6: STUDY 4.....	128
APPENDIX D: INFORMATION LETTER – CHAPTER 7: STUDY 5.....	134
APPENDIX E: INFORMED CONSENT FORM.....	140
APPENDIX F: MEDICAL QUESTIONNAIRE.....	141
APPENDIX G: PUBLICATION – CHAPTER 3: STUDY 1.....	144
APPENDIX H: PUBLICATION – CHAPTER 4: STUDY 2.....	145
APPENDIX I: PUBLICATION – CHAPTER 5: STUDY 3.....	146
APPENDIX J: PUBLICATION ACCEPTANCE – CHAPTER 6: STUDY 4.....	147
APPENDIX K: 2018 INTERNATIONAL CONFERENCE FOR STRENGTH TRAINING (ICST) POSTER.....	148
APPENDIX L: RESPONSE TO EXAMINERS’ COMMENTS.....	149

LIST OF TABLES

TABLE 1. MAIN FEATURES OF DEVICES MEASURING VELOCITY.	11
TABLE 2. RECOMMENDATIONS FOR THE SMALLEST DETECTABLE DIFFERENCE OF PEAK VELOCITY (PV), MEAN PROPULSIVE VELOCITY (MPV), AND MEAN VELOCITY (MV) AT 20%, 40%, 60%, 80%, 90%, AND 100% 1RM.....	67
TABLE 3. DESCRIPTION OF THE EXPERIMENTAL SESSIONS.....	75
TABLE 4. MEAN \pm SD DESCRIPTION OF EACH EXPERIMENTAL SESSION.	79
TABLE 5. DESCRIPTIVE CHARACTERISTICS OF PARTICIPANTS IN THE VBT AND PBT GROUPS...	91
TABLE 6. WITHIN GROUP COMPARISONS FOR PRE- AND POST-PERFORMANCE MEASURES, DIFFERENCES, PERCENT CHANGES, AND STATISTICAL ANALYSES.	100
TABLE 7. BETWEEN GROUPS COMPARISON OF TESTING MEASURES AT PRE- AND POST-SIX WEEKS OF SQUAT TRAINING.....	101

LIST OF FIGURES

FIGURE 1. 1RM - MEAN VELOCITY AT 100% 1RM ($1RM_{V1RM}$) PREDICTION METHOD	14
FIGURE 2. 1RM - MINIMUM VELOCITY THRESHOLD ($1RM_{MVT}$) PREDICTION METHOD.....	15
FIGURE 3. 1RM - LOAD AT ZERO VELOCITY ($1RM_{LD0}$) PREDICTION METHOD.	16
FIGURE 4. FV AND LV RELATIONSHIPS ($1RM_{FV}$) PREDICTION METHOD.	18
FIGURE 5. MEAN AND PEAK VALUES OF VELOCITY, FORCE, AND POWER. ABBREVIATION: 1RM, 1-REPETITION MAXIMUM. *SIGNIFICANT DIFFERENCES BETWEEN PUSH AND LABORATORY METHODS. #SIGNIFICANT DIFFERENCES BETWEEN GYMAWARE AND LABORATORY METHODS.	31
FIGURE 6. VALIDITY OF THE PUSH AND GYMAWARE FOR THE MEASUREMENT OF MEAN VELOCITY (MV), PEAK VELOCITY (PV), MEAN FORCE (MF), PEAK FORCE (PF), MEAN POWER (MP), AND PEAK POWER (PP). FOREST PLOTS DISPLAYING (A) PEARSON CORRELATION COEFFICIENT, (B) COEFFICIENT OF VARIATION, (C) EFFECT-SIZE ESTIMATES, AND STANDARD ERROR OF THE ESTIMATE FOR (D) MY AND PV, (E) MF AND PF, AND (F) MP AND PP.....	32
FIGURE 7. VALIDITY OF MEAN VELOCITY IN THE BACK SQUAT FOR THE PUSH AND GYMAWARE DEVICES AT 20%, 40%, 60%, 80%, 90%, AND 100% OF 1-REPETITION MAXIMUM (1RM) COMPARED WITH LABORATORY METHODS. FOREST PLOTS DISPLAYING (A) PEARSON CORRELATION COEFFICIENT, (B) COEFFICIENT OF VARIATION, (C) EFFECT-SIZE ESTIMATES, AND (D) STANDARD ERROR OF THE ESTIMATE. ABBREVIATION: 1RM, 1-REPETITION MAXIMUM. AREA SHADED IN GREY INDICATES THE ZONE OF ACCEPTABLE VALIDITY. ERROR BARS INDICATE 95% CONFIDENCE LIMITS.....	33
FIGURE 8. VALIDITY OF PEAK VELOCITY IN THE BACK SQUAT FOR THE PUSH AND GYMAWARE DEVICES AT 20%, 40%, 60%, 80%, 90%, AND 100% OF 1-REPETITION MAXIMUM (1RM) COMPARED WITH LABORATORY METHODS. FOREST PLOTS DISPLAYING (A) PEARSON CORRELATION COEFFICIENT, (B) COEFFICIENT OF VARIATION, (C) EFFECT-SIZE ESTIMATES, AND (D) STANDARD ERROR OF THE ESTIMATE. AREA SHADED IN GREY INDICATES THE ZONE OF ACCEPTABLE VALIDITY. ERROR BARS INDICATE 95% CONFIDENCE LIMITS.	34
FIGURE 9. VALIDITY OF MEAN FORCE IN THE BACK SQUAT FOR THE PUSH AND GYMAWARE DEVICES AT 20%, 40%, 60%, 80%, 90%, AND 100% OF 1-REPETITION MAXIMUM (1RM) COMPARED WITH LABORATORY METHODS. FOREST PLOTS DISPLAYING (A) PEARSON CORRELATION COEFFICIENT, (B) COEFFICIENT OF VARIATION, (C) EFFECT-SIZE ESTIMATES,	

AND (D) STANDARD ERROR OF THE ESTIMATE. AREA SHADED IN GREY INDICATES THE ZONE OF ACCEPTABLE VALIDITY. ERROR BARS INDICATE 95% CONFIDENCE LIMITS.	35
FIGURE 10. VALIDITY OF PEAK FORCE IN THE BACK SQUAT FOR THE PUSH AND GYMAWARE DEVICES AT 20%, 40%, 60%, 80%, 90%, AND 100% OF 1-REPETITION MAXIMUM (1RM) COMPARED WITH LABORATORY METHODS. FOREST PLOTS DISPLAYING (A) PEARSON CORRELATION COEFFICIENT, (B) COEFFICIENT OF VARIATION, (C) EFFECT-SIZE ESTIMATES, AND (D) STANDARD ERROR OF THE ESTIMATE. AREA SHED IN GREY INDICATES THE ZONE OF ACCEPTABLE VALIDITY. ERROR BARS INDICATE 95% CONFIDENCE LIMITS.	37
FIGURE 11. VALIDITY OF MEAN POWER IN THE BACK SQUAT FOR THE PUSH AND GYMAWARE DEVICES AT 20%, 40%, 60%, 80%, 90%, AND 100% OF 1-REPETITION MAXIMUM (1RM) COMPARED WITH LABORATORY METHODS. FOREST PLOTS DISPLAYING (A) PEARSON CORRELATION COEFFICIENT, (B) COEFFICIENT OF VARIATION (C) EFFECT-SIZE ESTIMATES, AND (D) STANDARD ERROR OF THE ESTIMATE. AREA SHADED IN GREY INDICATES THE ZONE OF ACCEPTABLE VALIDITY. ERROR BARS INDICATE 95% CONFIDENCE LIMITS.	39
FIGURE 12. VALIDITY OF PEAK POWER IN THE BACK SQUAT FOR THE PUSH AND GYMAWARE DEVICES AT 20%, 40%, 60%, 80%, 90%, AND 100% OF 1-REPETITION MAXIMUM (1RM) COMPARED WITH LABORATORY METHODS. FOREST PLOTS DISPLAYING (A) PEARSON CORRELATION COEFFICIENT, (B) COEFFICIENT OF VARIATION, (C) EFFECT-SIZE ESTIMATES, AND (D) STANDARD ERROR OF THE ESTIMATE. AREA SHADED IN GREY INDICATES THE ZONE OF ACCEPTABLE VALIDITY. ERROR BARS INDICATE 95% CONFIDENCE LIMITS.	40
FIGURE 13. PREDICTED 1RM FROM THE LOAD–VELOCITY RELATIONSHIP BASED ON 20–60% OF 1RM (A), 20–80% OF 1RM (B), 20–90% OF 1RM (C) OF A TYPICAL SAMPLE. FOR THIS CASE, THE PREDICTED 1RM WAS 191.2 KG (A), 186.3 KG (B) AND 184.8 KG (C), RESPECTIVELY.....	45
FIGURE 14. EXPERIMENTAL PROTOCOL. SESSION 1, TRIAL 1, 2, AND 3 EACH COMPRISED A 1RM ASSESSMENT SEPARATED BY 48 HOURS.	46
FIGURE 15. INDIVIDUAL VARIATION OF 1RM AND PREDICTED 1RMS BETWEEN TRIALS. THE SHADED BARS INDICATE THE GROUP MEAN FOR THAT TRIAL. *SIGNIFICANT DIFFERENCE BETWEEN 1RM AND PREDICTED 1RM UP TO 90%, 80%, AND 60% 1RM; #SIGNIFICANT DIFFERENCES BETWEEN THE 90% AND 60% 1RM PREDICTIONS.....	48
FIGURE 16. RELIABILITY BETWEEN TRIALS OF THE 1RM AND PREDICTED 1RM UP TO 60%, 80%, AND 90% 1RM. FOREST PLOTS DISPLAYING: (A) SEM STANDARD ERROR OF THE MEASUREMENT, (B) CV COEFFICIENT OF VARIATION, (C) ICC INTRACLAS CORRELATION	

COEFFICIENT, AND (D) THE ES EFFECT SIZE ESTIMATES. ERROR BARS INDICATE 95% CONFIDENCE LIMITS OF THE MEAN DIFFERENCE BETWEEN TRIALS.....	51
FIGURE 17. VALIDITY OF THE PREDICTED 1RM UP TO 60%, 80, AND 90% 1RM COMPARED WITH 1RM. FOREST PLOTS DISPLAYING: (A) SEE STANDARD ERROR OF THE ESTIMATE, (B) CV COEFFICIENT OF VARIATION, (C) PEARSON CORRELATION COEFFICIENT, AND (D) THE ES EFFECT SIZE ESTIMATES. ERROR BARS INDICATE 95% CONFIDENCE LIMITS OF THE MEAN DIFFERENCE BETWEEN 1RM AND PREDICTED 1RM.	52
FIGURE 18. THE AVERAGE ABSOLUTE DIFFERENCE BETWEEN THE 1RM AND PREDICTED 1RMS UP TO 60%, 80%, AND 90% 1RM.....	54
FIGURE 19. GROUP MEAN (SD) VALUES FROM THREE 1RM TRIALS FOR PV, MPV, AND MV AT 20%, 40%, 60%, 80%, 90%, AND 100% 1RM LOAD. ABBREVIATIONS: 1RM, 1- REPETITION MAXIMUM; PV, PEAK VELOCITY; MPV, MEAN PROPULSIVE VELOCITY; MV, MEAN VELOCITY.....	64
FIGURE 20. RELIABILITY OF PV, MPV, AND MV IN THE BACK SQUAT AT 20%, 40%, 60%, 80%, 90%, AND 100% 1RM. FOREST PLOTS DISPLAYING ICC (A), CV (B), ES ESTIMATES (C), AND SEM (D). GARY-SHADED AREA INDICATES THE ZONE OF ACCEPTABLE RELIABILITY. ERROR BARS INDICATE 95% CONFIDENCE LIMITS. RIGHT Y-AXES CONTAIN THE MEAN AND 95% CONFIDENCE LIMITS. ABBREVIATIONS: PV, PEAK VELOCITY; MPV, MEAN PROPULSIVE VELOCITY; MV, MEAN VELOCITY; 1RM, 1-REPETITION MAXIMUM; ICC, INTRACLASS CORRELATION COEFFICIENT; CV, COEFFICIENT OF VARIATION; ES, EFFECT SIZE.	65
FIGURE 21. INDIVIDUAL VARIATION AND THE GROUP MEAN OF PV (A), MPV (B), AND MV (C) AT 100% 1RM FOR TRIALS 1–3. THE BLACK CIRCLES INDICATE THE GROUP MEAN FOR THE RELEVANT 1RM TRIAL. PV INDICATES PEAK VELOCITY; MPV, MEAN PROPULSIVE VELOCITY; MV, MEAN VELOCITY; 1RM, 1-REPETITION MAXIMUM.	68
FIGURE 22. LOAD–VELOCITY PROFILES OBTAINED FROM GROUP MEAN DATA (SD) USING A SECOND-ORDER POLYNOMIAL FIT AND A LINEAR REGRESSION FIT BETWEEN RELATIVE LOAD AND (A) PV FROM 20% TO 100% 1-RM (PV20–100%), (B) MPV FROM 20% TO 90% 1-RM (MPV20–90%), AND (C) MV FROM 20% TO 90% 1-RM (MV20–90%). PV INDICATES PEAK VELOCITY; 1-RM, 1-REPETITION MAXIMUM; MPV, MEAN PROPULSIVE VELOCITY; MV, MEAN VELOCITY.....	69
FIGURE 23. INDIVIDUAL VARIATION OF MEAN REPETITION VALUES OF MEAN VELOCITY (MV) AND PEAK VELOCITY (PV) FOR THE 1RM-PERCENT-BASED TRAINING (PBT), LOAD-	

VELOCITY PROFILE (LVP), FIXED SETS 20% VELOCITY LOSS THRESHOLD (FS_{VL20}), AND VARIABLE SETS 20% VELOCITY LOSS THRESHOLD (VS_{VL20}) SESSIONS. THE SHADED BARS INDICATE THE GROUP MEAN, AND THE FIGURE LEGEND CONTAINS THE NUMERICAL GROUP VELOCITIES FOR THE EXPERIMENTAL SESSIONS. #SIGNIFICANT DIFFERENCE BETWEEN AN EXPERIMENTAL SESSION AND PBT. 80

FIGURE 24. INDIVIDUAL VARIATION OF MEAN REPETITION VALUES OF MEAN FORCE (MF) AND PEAK FORCE (PF) FOR THE 1RM-PERCENT-BASED TRAINING (PBT), LOAD-VELOCITY PROFILE (LVP), FIXED SETS 20% VELOCITY LOSS THRESHOLD (FS_{VL20}), AND VARIABLE SETS 20% VELOCITY LOSS THRESHOLD (VS_{VL20}) SESSIONS. THE SHADED BARS INDICATE THE GROUP MEAN, AND THE FIGURE LEGEND CONTAINS THE NUMERICAL GROUP FORCE VALUES FOR THE EXPERIMENTAL SESSIONS..... 81

FIGURE 25. INDIVIDUAL VARIATION OF MEAN REPETITION VALUES OF MEAN POWER (MP) AND PEAK POWER (PP) FOR THE 1RM-PERCENT-BASED TRAINING (PBT), LOAD-VELOCITY PROFILE (LVP), FIXED SETS 20% VELOCITY LOSS THRESHOLD (FS_{VL20}), AND VARIABLE SETS 20% VELOCITY LOSS THRESHOLD (VS_{VL20}) SESSIONS. THE SHADED BARS INDICATE THE GROUP MEAN, AND THE FIGURE LEGEND CONTAINS THE NUMERICAL GROUP POWER VALUES FOR THE EXPERIMENTAL SESSIONS..... 83

FIGURE 26. INDIVIDUAL VARIATION DURING THE 1RM-PERCENT-BASED TRAINING (PBT), LOAD-VELOCITY PROFILE (LVP), FIXED SETS 20% VELOCITY LOSS THRESHOLD (FS_{VL20}), AND VARIABLE SETS 20% VELOCITY LOSS THRESHOLD (VS_{VL20}) SESSIONS FOR VALUES OF MEAN REPETITION LOAD (ML), MEAN REPETITION WORK (MW), TOTAL SESSION LOAD (TL) AND TOTAL SESSION WORK (TW), THE SHADED BARS INDICATE THE GROUP MEAN, AND THE FIGURE LEGEND CONTAINS THE NUMERICAL MEAN GROUP VALUES FOR THE EXPERIMENTAL SESSIONS..... 84

FIGURE 27. INDIVIDUAL VARIATION DURING THE 1RM-PERCENT-BASED TRAINING (PBT), LOAD-VELOCITY PROFILE (LVP), FIXED SETS 20% VELOCITY LOSS THRESHOLD (FS_{VL20}), AND VARIABLE SETS 20% VELOCITY LOSS THRESHOLD (VS_{VL20}) SESSIONS FOR VALUES OF MEAN ECCENTRIC TIME UNDER TENSION (ETUT), MEAN CONCENTRIC TIME UNDER TENSION (CTUT), MEAN TOTAL TIME UNDER TENSION (TUT), TOTAL SESSION ECCENTRIC TIME UNDER TENSION (SETUT), TOTAL SESSION CONCENTRIC TIME UNDER TENSION (SCTUT) AND TOTAL SESSION TIME UNDER TENSION (STUT). THE SHADED BARS INDICATE THE GROUP MEAN, AND THE FIGURE LEGEND CONTAINS THE NUMERICAL MEAN

GROUP VALUES FOR THE EXPERIMENTAL SESSIONS. # SIGNIFICANT DIFFERENCE BETWEEN AND EXPERIMENTAL SESSION AND PBT.....	86
FIGURE 28. OVERALL EXPERIMENTAL STUDY DESIGN TIMELINE.	91
FIGURE 29. AN EXAMPLE OF CONVERTING A RELATIVE LOAD TABLE INTO A MEAN VELOCITY TABLE USING A LOAD-VELOCITY PROFILE OBTAINED FROM A REPRESENTATIVE PARTICIPANT.	93
FIGURE 30. SESSIONAL VALUES FOR (A) AVERAGE REPETITION LOAD (% 1RM), (B) AVERAGE REPETITION VELOCITY, (C) AVERAGE REPETITION VELOCITY DEVIATION COMPARED TO THE INTENDED VELOCITY FROM THE INDIVIDUALISED LOAD-VELOCITY PROFILE, (D) SESSION RATING OF PERCEIVED EXERTION [RPE]. *P < 0.05.	98
FIGURE 31. AVERAGE REPETITION LOAD FOR EACH SESSION OBTAINED FROM TWO INDIVIDUALS IN THE VBT GROUP COMPARED TO THE PBT GROUP. AVERAGE TRAINING LOAD (% 1RM) AND THE MAGNITUDE OF 1RM INCREASE ARE PROVIDED FOR THE TWO VBT INDIVIDUALS AND THE PBT GROUP.....	102
FIGURE 32. BETWEEN GROUP EFFECT SIZE COMPARISONS FOR THE CHANGES IN TESTING MEASURES.....	103
FIGURE 33. LOAD-VELOCITY PROFILES (USING MEAN VELOCITY) AT BASELINE (LVP-1), POST-TRAINING 1RM ASSESSMENT (LVP-2) AND POST-TRAINING LOAD-VELOCITY PROFILE ASSESSMENT (LVP-3). * DENOTES THAT LVP-2 VELOCITIES ARE SIGNIFICANTLY DIFFERENT TO LVP-1 AND LVP-2. # INDICATES THAT MV AT 100% 1RM WAS NOT INCLUDED IN THE LVPs SINCE IT IS NOT RELIABLE.....	105

ABBREVIATED TERMINOLOGY

1RM	One Repetition Maximum
1RM_{BW}	Body Weight 1RM Prediction Method
1RM_{FV}	Force-Velocity and Load-Velocity 1RM Prediction Method
1RM_{LD0}	Load at Zero Velocity 1RM Prediction Method
1RM_{MVT}	Minimum Velocity Threshold 1RM Prediction Method
1RM_{V1RM}	Velocity at 100% 1RM Prediction Method
COD	505 Change of Direction Assessment
CMJ	Countermovement Jump
CTUT	Mean Concentric Time Under Tension
CV	Coefficient of Variation
ES	Effect Size
ETUT	Mean Eccentric Time Under Tension
FS_{VL}	Fixed Sets Velocity Loss Threshold
GYM	GymAware
ICC	Intraclass Correlation Coefficient
LT	Linear Transducer
LVP	Load-Velocity Profile
MF	Mean Force
ML	Mean Repetition Load
MP	Mean Power
MPV	Mean Propulsive Velocity
MV	Mean Velocity
MW	Mean Repetition Work
PBT	1RM-Percent-Based Training
PF	Peak Force
PP	Peak Power
PUSH	PUSH Band
PV	Peak Velocity
RPE	Rating of Perceived Exertion
sCTUT	Total Session Concentric Time Under Tension
SEE	Standard Error of the Estimate
SEM	Standard Error of the Measurement
sETUT	Total Session Eccentric Time Under Tension
SSC	Stretch Shortening Cycle
sTUT	Total Session Time Under Tension
TL	Total Session Load
TUT	Time Under Tension
TW	Total Session Work
V_{1RM}	Mean Velocity at 1RM
VBT	Velocity-Based Training
VS_{VL}	Variable Sets Velocity Loss Threshold

LIST OF PUBLICATIONS AND PRESENTATIONS

PUBLICATIONS FORMING PART OF THIS THESIS

Chapter 2

Hughes, L., **Banyard, H.G.**, Dempsey, A.R., Scott, B.R. *Using load-velocity relationships to predict 1RM in free-weight exercise: a comparison of the different methods.* The Journal of Strength and Conditioning Research, 2018. (Epub ahead of print).

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Chapter 3

Banyard, H.G., Nosaka, K., Sato, K., & Haff, G.G. *Validity of various methods for determining velocity, force and power in the back squat.* International Journal of Sports Physiology and Performance, 2017. 12(9): p. 1170-1176.

Chapter 4

Banyard, H.G., Nosaka, K., & Haff, G.G. *Reliability and validity of the load-velocity relationship to predict the 1RM back squat.* The Journal of Strength and Conditioning Research, 2017. 31(7): p. 1897-1904.

Chapter 5

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Chapter 6

Banyard, H.G., Tufano, J.J., Delgado, J., Thompson, S., & Nosaka, K. *Comparison of velocity-based training and traditional 1RM-percent-based prescription on acute kinetic and kinematic variables.* International Journal of Sports Physiology and Performance, 2018. (Epub ahead of print).

N.B. Please note the formatting within this thesis may not coincide 100% with the published (or under-review) manuscripts listed above. For example, the referencing styles have been modified from the original published manuscript to ensure consistency throughout the entire thesis. However, the main body of text, figures, tables, and the actual references have not been altered in any way.

SCIENTIFIC CONFERENCE PRESENTATIONS RELATED TO THIS THESIS

Banyard, H.G., Nosaka, K., & Haff, G.G. (2015). Reliability and validity of the load-velocity relationship to predict the 1RM back squat. Presented at the Centre for Exercise and Sports Science Research (CESSR), School of Medical and Health Sciences, Perth, Western Australia, Australia.

Banyard, H.G., Nosaka, K., & Haff, G.G. (2015). Validity of the load-velocity relationship to predict the 1RM back squat. Presented at the University of Notre Dame School of Exercise and Health Sciences Research Seminar Series, Perth, Western Australia, Australia.

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Banyard, H.G., Nosaka, K., Vernon, A., & Haff, G.G. (2017). *The reliability of individualised load-velocity profiles.* Strength of Science – Audio Abstracts. <https://www.youtube.com/watch?v=YUUq6k2zLDs>

Banyard, H.G. (2017). Velocity-based training presentation: Australian Strength and Conditioning Association (ASCA) Workshop, Perth, Western Force Headquarters.

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Hughes, L., **Banyard, H.G.,** Dempsey, A.R., Peiffer, J., and Scott, B.R. *Using load-velocity relationships to quantify training induced fatigue.* The Journal of Strength and Conditioning Research, 2018 (Epub ahead of print).

CHAPTER 1

INTRODUCTION

BACKGROUND

Resistance training has been shown to attenuate the risk of injury and improve athletic performance [1-3]. Specifically, increasing maximal strength and power can translate to improvements in markers of performance such as running, jumping and change of direction [4-6]. In order to optimise strength and power development, strength and conditioning coaches can manipulate factors such as the type, order, volume, intensity (velocity) and load of exercise, as well as the rest periods between sets and exercises. Of these aforementioned factors, training velocity and training load are highly influential for augmenting strength and power adaptations [7]. One training load prescription method known as repetition maximum (RM) training requires a maximum number of repetitions (10RM, 5RM etc.) to be lifted in each exercise set that may be completed to concentric muscular failure [8]. However, training to concentric muscular failure can induce excessive fatigue and diminish the force generating capacity in subsequent sets leading to lower gains in strength and power adaptations over time [9-11], particularly in resistance-trained athletes [12, 13]. In addition to these findings, research has also shown that performing all repetitions with maximal concentric velocity can result in significant enhancement of both strength and power compared to training to failure [13, 14]. Thus, to maximise gains in strength and power, it may be advised that athletes lift with maximal concentric velocity but not to maximal concentric muscular failure.

Due to the limitations of RM training, it is more commonplace for athletes to train with loads prescribed as a percentage of a 1-repetition maximum (1RM), known as percent-based training (PBT). This method is quite simple, and allows strength and conditioning coaches to periodise resistance training sessions to accommodate for recovery and improve physical abilities critical to sports performance [15]. However, even though programming from PBT is practical and can be managed with relative ease when training a large team of athletes, it does not account for day-to-day fluctuations in maximal strength or performance that can occur due to training induced fatigue [16], or elevated psychological stress levels [17], among others factors. Therefore, more precise objective methods to monitor and prescribe individualised sessional training loads may be of particular interest to strength and conditioning professionals.

Performing resistance training with maximal attainable concentric velocities gives rise to another alternative to conventional PBT methods: velocity-based training (VBT). Importantly, performing repetitions with maximal intended velocity can provide greater neuromuscular stimuli and increases in training adaptation (maximal strength and power) compared to training to failure [13], or with deliberately slower velocity repetitions [14]. However, if an exercise is performed with maximal voluntary effort, the velocity of the movement will decline within a set as fatigue ensues [18]. Furthermore, continued training with significant declines in repetition velocity can induce excessive fatigue that is detrimental to power output [19]. By monitoring velocity and providing immediate repetition feedback, coaches can make objective training based decisions limiting the number of slower velocity repetitions performed with sub-optimal velocity and power outputs. This is pertinent for athletes whose training goal is primarily focused on increased activation and firing frequency of type II muscle fibres which contribute to enhancing the rate of force development (RFD) that can lead to increases in strength and power development [20, 21]. Therefore, VBT allows a coach to objectively modify a resistance training session if required [13, 22].

At the start of this doctoral work in 2014, a major limitation of VBT was the availability of affordable technology that could accurately measure velocity. As a consequence, new and less expensive devices were developed but their accuracy remained uncertain. For example, a relatively inexpensive, wearable inertial sensor (PUSH band, PUSH Inc., Toronto, Canada) was developed to assess velocity, force and power in a myriad of resistance training exercises. It was suggested that this device was highly accurate but studies to verify these claims were required. Since training load and training volume adjustments using VBT are based on minor yet significant changes in velocity, it was, and still is, important to discern the accuracy of data collected from such devices across a variety of loads and exercises.

One use of VBT is to predict 1RM from the velocities of sets performed with submaximal loads [23]. The 1RM assessment is a well-established reliable method for determining maximal strength [24]. However, maximal strength can fluctuate due to fatigue or training adaptation [22]. Furthermore, 1RM assessments are time consuming and it is not always desirable for athletes to lift with maximal loads throughout a training season. Therefore, 1RM prediction methods performed with submaximal loads were desired. Due to the almost perfect correlation and linearity of the load-velocity relationship, it was thought possible for sessional 1RM predictions to be made by extrapolating the load (100% 1RM) from the intersection of the velocity at 1RM (V_{1RM}) using the individual's load-velocity profile (LVP) regression line [22]. Theoretically, if 1RM predictions

were precise then the velocities performed during the warm-up sets of a training session could be used to calculate and monitor day-to-day variation in maximal strength. As a consequence, training load could be modified to account for individual rates of recovery and adaptation. Importantly, for this method to be able to predict changes in maximal strength when athletes are fatigued, it was crucial to establish whether 1RM predictions are stable in non-fatigued conditions. Such a finding would be of great interest to strength coaches who have to routinely track their athlete's changes in maximal strength throughout a season by having them perform 1RM assessments, which can take valuable time away from training.

A previously unexplored VBT approach was the monitoring of velocity between training sessions to modify training load. The inverse linear relationship between load and velocity shows that if maximal concentric effort is provided, lighter loads can be lifted with faster velocities than heavier loads [23]. Furthermore, when maximal concentric effort is given within a training set, the velocity will eventually decline when neuromuscular fatigue develops [18]. A characteristic of VBT was the apparent stability of velocity between training sessions. However, evidence to support this assertion was lacking in 2014. If velocity was found to be reliable across the relative load spectrum then an individualised LVP could be established to create velocity targets. This would then allow an individual to monitor the velocity of their warm-up repetitions (submaximal loads) and track their performance or readiness to train against the velocity targets. This is thought to be practically useful since it is hypothesized that any meaningful increase or decrease in velocity between training sessions compared to a baseline LVP will reflect an increase or decrease in strength resultant from training adaptation or residual fatigue. Therefore, this VBT method could be useful for objective training load prescription based on the sessional velocity performance of an individual and their readiness to train. However, for the LVP approach of VBT to be employed as a training method, the reliability of velocity between sessions needed to be investigated so that meaningful changes in velocity could be established.

Another approach to VBT is the use of velocity loss thresholds to modify training volume prescription (number of repetitions per set). This particular VBT method dictates that a set can be terminated when repetitions are not performed above a certain velocity which is normally determined as a percentage of the fastest repetition in the first set of a training session [21]. Padulo et al. [13] implemented a 20% velocity loss threshold and showed that maintaining at least 80% of MV during training results in greater increases in Smith machine bench press 1RM compared to sets performed to failure. Similarly, Pareja-Blanco et al. [20] also showed that using a 20% velocity loss threshold for the Smith machine back squat resulted in similar increases in predicted

1RM strength but greater increases in power output compared to a 40% velocity loss threshold. In 2014, all of the VBT studies had been performed on a Smith machine. Although these studies have merit and provided the basis of VBT research, no studies had investigated VBT methods in large mass free-weight exercises that require movements in both the vertical and horizontal planes, movements that are extensively utilised in practice.

At the commencement of this thesis project in the beginning of 2014, it was known that VBT methods could provide greater neuromuscular stimuli and increase training adaptations compared to training to failure [13]. However, it was not known whether VBT methods would elicit greater long-term adaptations to strength and power compared to more traditional PBT methods. It was conceivable that VBT may be more beneficial than PBT since it provides a more objective method for adjusting resistance-training sessions to account for individual differences in the rate of training adaptation. Additionally, even though long-term adaptations in strength and power may occur from VBT, the magnitude of velocity decline within a single session was unclear using different VBT methods. Thus, investigating the acute decline in kinetic and kinematic variables following a VBT session was required in order to provide programmatic guidance to strength coaches who may choose to implement these novel methods to adjust resistance training load or volume.

CENTRAL AIM

The central aim of this thesis was to investigate the efficacy of using velocity as an objective method for adjusting training load to account for individual differences in the rate of training adaptation, and determine whether VBT methods are more favourable for enhancing strength and power compared to more traditional PBT methods in male, strength-trained participants.

CENTRAL HYPOTHESIS

It was hypothesised that VBT would accurately monitor recovery within a training session based on the velocity of repetitions performed within the warm-up, and when applied in a training study, VBT would result in greater adaptations to strength and power compared to PBT.

The present thesis project consisted of five studies (Study 1 – Study 5), and the aim and hypothesis of each study are shown below.

Specific Aim of Study 1 (Chapter 3): To investigate the ability of two field-based devices to accurately measure velocity, force and power in the back squat exercise compared with laboratory based equipment.

Hypothesis: It was hypothesized that both the accelerometer and LT device would accurately measure all of the kinetic and kinematic data through the relative load spectrum, and either device could be used for VBT.

Specific Aim of Study 2 (Chapter 4): To determine the reliability and validity of the load-velocity relationship to predict the back squat 1RM.

Hypothesis: It was hypothesized that the load-velocity relationship would be highly reliable and valid for 1RM predictions, and could be used as a method to modify training load for VBT.

Specific Aim of Study 3 (Chapter 5): To examine the reliability of PV, MPV and MV in the development of LVPs.

Hypothesis: It was hypothesized that all three concentric velocities would be reliable, and could be used to develop LVPs, which in turn could be used to objectively modify training load prescription based on the sessional velocity performance of an individual.

Specific Aim of Study 4 (Chapter 6): To compare the kinetic and kinematic data from a PBT session and three different VBT sessions.

Hypothesis: It was hypothesized that all three VBT sessions would permit faster average session velocities and power output than a PBT session.

Specific Aim of Study 5 (Chapter 7): To compare the changes in strength and power between VBT and PBT groups.

Hypothesis: It was hypothesized that VBT group would result in more favourable adaptations to strength and power compared to PBT group.

THESIS OVERVIEW

This thesis consists of eight chapters. Chapter 2 reviews the key literature surrounding VBT including the main velocity measuring technology, sessional 1RM prediction methods, and the current applied VBT methods. Chapter 3 presents the results of two field-based devices to accurately measure velocity, force and power, which has been accepted for publication in the *International Journal of Sports Physiology and Performance*. Chapter 4 presents the findings of the reliability and validity of the load-velocity relationship to predict the back squat 1RM which was accepted for publication in the *Journal of Strength and Conditioning Research*. The reliability of PV, MPV and MV is discussed in Chapter 5, which was accepted for publication in the *International Journal of Sports Physiology and Performance*. Chapter 6 presents the kinetic and kinematic data from PBT and different VBT sessions which has recently been accepted for publication in the *International Journal of Sports Physiology and Performance*. Chapter 7 presents the findings of the training study between VBT and PBT groups. Last, a general summary and limitations is presented in Chapter 8 which also contains recommendations for future research.

CHAPTER 2

REVIEW OF THE LITERATURE

CHAPTER OVERVIEW

This chapter briefly introduces VBT with particular focus directed at its use in maximising strength and power adaptations, which is then followed by five main sections. Firstly, this review will discuss the advantages and limitations of different velocity measuring devices. Section two describes the accuracy of numerous 1RM prediction methods and their limitations for sessional modification of training load. The third section will discuss the paucity of research examining the stability of velocity and which velocity measures can be used to accurately evaluate and monitor training. LVPs will then be discussed in section four with specific mention to the exercises that have been investigated, the use of LVPs in monitoring an individual's readiness to train, and the ability of LVPs to track changes in strength. Finally, section five will outline the literature related to the current implementation and interpretation strategies of VBT methods, more specifically related to enhancing maximal strength and power through the use of velocity loss thresholds.

INTRODUCTION

Traditional PBT involves the prescription of relative submaximal loads from a one-repetition maximum (1RM) assessment. Even though PBT provides a practical means to prescribe relative loads and training volume, maximal strength (i.e. 1RM load) can increase by 10% within a few weeks due to training adaptation [13]. Moreover, prescribing training load from pre-determined 1RM loads does not account for daily fluctuations in maximal strength, which can be attributed to physical and psychological stressors [25]. As a result, continued training with prescribed lifting loads from an out-dated 1RM may not optimise the neuromuscular stimuli required to maximise adaptation and may also be inappropriate for training individuals on a daily basis whose performance can fluctuate from residual fatigue. Therefore, alternative methods for prescribing resistance training have been established.

Due to commercially available kinetic and kinematic technology, researchers have investigated the use of immediate feedback using VBT methods to objectively manipulate resistance-training volume within a training session [20, 26]. Research has established four distinct benefits of monitoring velocity in training. Firstly, movement velocity is critical to training

intensity, such that if maximal effort is provided throughout the concentric phase of a lift, there will be greater force production [27, 28] and recruitment of Type II muscle fibres [29] compared to self-selected [13] or deliberately slower concentric muscle actions [14], which increases the neuromuscular stimuli associated with strength and power development [13]. Secondly, the onset of fatigue becomes apparent if an exercise is performed with maximal concentric effort and the repetition velocity declines within a set [18, 30]. Thirdly, due to the apparent stability of movement velocity at any relative load [31], any fluctuations in velocity beyond the normal variation observed between training sessions is likely to reflect fatigue or gains in strength. Fourth, immediate velocity biofeedback to the users can enhance performance output so that individuals can attempt to “beat” a previous repetition or sets velocity value. For these reasons, monitoring velocity in strength training sessions to manipulate relative loads and training volume has increased in popularity.

Manufacturers have developed velocity measurement devices to accurately assess eccentric and concentric velocities. Specifically, VBT is often centred on one of three different methods to quantify concentric velocity including peak velocity (PV), mean velocity (MV) and mean propulsive velocity (MPV). PV is determined as the maximum value collected during the concentric phase of a repetition and is a pertinent measure for explosive exercises whereas MV is calculated as the average velocity during the entire concentric action. MV is typically monitored through the entire phase of non-aerial exercises/movements (i.e. a part of the body remains in contact with the ground, machine, or other resistive device), but since there can be a large deceleration phase with light and medium loads, MV is thought to underestimate an individual’s true neuromuscular potential for some exercises [32]. As a result, many research papers monitoring velocity will measure and report MPV, which is the average of the concentric phase when acceleration is greater than $0 \text{ m}\cdot\text{s}^{-2}$. Importantly, MPV measures the “propulsive” phase of a repetition, which is thought to better represent the true neuromuscular potential of an individual compared to MV [32].

The foundation of VBT is the inverse linear relationship that exists between load and velocity, meaning that heavier loads cannot be lifted with the same concentric velocity as lighter loads if an individual provides maximal concentric effort. The current body of scientific literature suggests that all repetitions performed during a maximal strength-oriented training phase should be performed at maximal concentric velocity but not to concentric muscular failure if the goal is to enhance strength and power, regardless of training load [12, 13]. However, there may be some value in a hypertrophy block pushing closer to failure, sequenced prior to a maximal strength-

oriented training phase that is further from failure, which in the context of a long term periodised plan could conceivably aid strength gains over time. Recent studies have examined different VBT methods in resistance training sessions in an attempt to modify training load or volume and account for day-to-day fluctuations in performance [20, 26, 33]. These VBT methods include i) using velocity to predict 1RM; ii) creating an individualised LVP; and iii) implementing velocity loss thresholds. The objective of this review is to discuss: the current literature surrounding the aforementioned VBT methods; how these methods have been applied to modify resistance training and optimise strength and power adaptation; and examine the limitations which guide the direction of this thesis.

DEVICES MEASURING VELOCITY

Motion Analysis

In resistance training, linear transducers (LT), accelerometer-based devices, three-dimensional (3D) and two-dimensional (2D) motion analysis systems can be used to assess velocity. 3D and 2D motion analysis systems calculate velocity by measuring the distance an object has moved with respect to time. Even though 3D motion analysis systems are often used as the gold standard criterion measurement to assess barbell velocity, the analysis required to extract the data from 3D motion analysis systems have been labour intensive and unable to provide instantaneous repetition feedback. Importantly, when an individual employs VBT, immediate feedback for each repetition is required to make training decisions. Therefore, using 3D motion analysis systems as a practical tool to monitor velocity and provide instantaneous feedback for multiple athletes during VBT have not been ideal. To overcome the labour-intensive nature of video analysis in resistance training research, some companies have improved upon the speed of repetition feedback in 2D motion analysis systems but to our knowledge, no immediate feedback improvements have been made to 3D motion analysis systems making them impractical for VBT.

Sañudo and colleagues [34] recently validated a free 2D video analysis software program (Kinovea 0.8.15, www.kinovea.org, France) to quantify PV and mean propulsive velocity (MPV) of the Smith machine bench press at 20 kg, 30 kg, 40 kg, 50 kg, 60 kg, 70 kg, and 80 kg in 21 recreationally trained men. It was reported that the software provided accurate assessments of PV and MPV with instantaneous repetition feedback when compared to an LT (T-Force, T-Force System Ergotech, Murcia, Spain). However, on closer inspection, the correlation findings ($r = 0.47 - 0.99$), Bland Altman plots (PV: bias = $-0.30 - -0.60 \text{ m}\cdot\text{s}^{-1}$, limits of agreement = $0.00 - -1.10$

$\text{m}\cdot\text{s}^{-1}$; MPV: bias = $-0.20 - -0.40 \text{ m}\cdot\text{s}^{-1}$, limits of agreement = $-0.10 - -0.65 \text{ m}\cdot\text{s}^{-1}$) and group mean differences (PV: $-0.23 - -0.59 \text{ m}\cdot\text{s}^{-1}$; MPV: $-0.14 - -0.43 \text{ m}\cdot\text{s}^{-1}$) suggest the Kinovea analysis software significantly over predicted ($p < 0.05$) PV and MPV and the validity was highly questionable due to the high variability seen with all loads assessed. In addition, other measures of validity such as the coefficient of variation (CV) and standard error of the estimate (SEE) were not reported, making a more accurate comparison and appraisal of these results problematic.

Recent advancements in smartphone technologies with high-speed 2D cameras have aided the development of smartphone applications to measure barbell velocity [35]. Most individuals own and carry a smartphone, making it a practical tool for monitoring velocity. Although the velocity feedback is not instantaneous following each repetition, the analysis required to extract the velocity data (e.g. initial measurement of range of motion, selecting the start and finish of a repetition; entering barbell load) takes less than a minute, which is a significant time reduction compared to traditional 2D data extraction methods. Thus, the introduction of smartphone applications has significantly reduced the data acquisition time for 2D motion analysis to assess velocity. In addition, the reliability and validity of a smartphone application to assess velocity has recently been established. It was found that the smartphone application (Powerlift iOS app) had acceptable reliability (ICC = $0.91 - 0.99$) and validity ($r = 0.97 - 0.98$; SEE = $0.03 - 0.05 \text{ m}\cdot\text{s}^{-1}$) for measuring MV compared with an LT (SmartCoach Power Encoder, SmartCoach Europe, Stockholm, Sweden) when participants performed six incremental sets (roughly 50%, 60%, 70%, 80%, and 90% 1RM)) for the bench press, full depth back squat and hip thrust exercises. Although these results sound promising, the difficulty with using smartphone applications to measure velocity is that it requires an individual to record and analyse the data for each repetition which is acceptable if you are monitoring one athlete but could be tedious and time consuming if this method were to be applied to monitor a large squad of athletes. Furthermore, researchers in a laboratory environment ensure consistent distance and level phone position when filming an individual, whilst lay public purchasers of smartphone applications may not be as precise, which might make the published reliability outcomes unrealistic outside of the laboratory setting.

To overcome the issues associated with video analysis in VBT research, many commercial devices have been developed that provide immediate and accurate repetition feedback, which allows coaches to make immediate training decisions that are data-driven. These devices have inspired researchers to conduct numerous studies assessing movement velocity in a variety of exercises. Popular devices to monitor velocity include LTs, accelerometer-based devices and smartphone applications, among others (Table 1). Each device differs in the accuracy, method of

data acquisition, analysis software, ability to provide instantaneous repetition feedback, cost, practicality and transportability.

Table 1. Main features of devices measuring velocity.

Device	Accuracy	Sampling Frequency (Hz)	Cost	Instantaneous Repetition Feedback	Portable
<u>Linear Transducers</u>					
GymAware	Almost Perfect	2000	Moderate	Yes	Yes
T-FORCE	Almost Perfect	1000	Moderate	Yes	No
Celesco	Almost Perfect	1000	Moderate	Yes	No
SmartCoach	Almost Perfect	1000	Moderate	Yes	No
<u>3D & 2D Motion Analysis</u>					
(3D) VICON	Almost Perfect	200	High	No	No
(2D) Video Camera	Almost Perfect	125 - 1000	Low- Moderate	No	Yes
(2D) Smartphone app	High	240	Low	Yes	Yes
<u>Accelerometer-based Technologies</u>					
PUSH	Moderate	200	Low	Yes	Yes
Beast Sensor	High	50	Low	Yes	Yes

Linear Transducer (LT) Devices

LTs are popular in laboratories and among professional sporting teams since they are small, reliable, valid, practical, and provide a copious amount of information regarding the performance of an athlete (Table 1) [36, 37]. To measure movement velocity, a sensor in the LT detects the changes in cable displacement with respect to time. Even though LTs can monitor velocity for most barbell resistance training exercises, they require the use of a cable/tether attachment to the barbell, which may restrict its suitability for some exercises. Furthermore, purchasing multiple LTs can be cost prohibitive for non-professional sporting teams, limiting the use of multiple LT systems to only the few athletes and coaches that can afford them. Nevertheless, with a bit of planning, a single LT unit can be utilised with many athletes during a single training session, which can make them relatively cost effective for a large sporting team, particularly compared to other laboratory equipment such as isokinetic dynamometers and force plates. Therefore, if the moderate to high cost (approximately US\$2000) is not a burden, an LT can provide an effective option for measuring velocity in resistance training.

One key thing to consider when using LTs during free-weight exercises is the location of the cable/tether attachment on the barbell with respect to the measured displacement of a repetition.

For exercises performed in a Smith machine, the barbell is connected to a rigid frame and has very limited, if any, flexibility, even at high loads. This means that as long as the cable is positioned in the same direction as the vertical bar path, the LT will accurately measure the movement velocity of a repetition. However, in free-weight exercises the barbell can distort at either end during the eccentric and concentric phases of a repetition when athletes lift with high absolute loads [38]. This suggests the displacement and associated velocity during a repetition will likely differ between the middle of the barbell (where the lifter is positioned) and the attachment point of the LT cable/tether (at the end of the barbell). For example, Appleby et al. [38] et al. had 12 well-trained rugby union players complete two sets of two repetitions at 70%, 80%, and 90% 1RM for the 90° free-weight back squat exercise performed with maximal concentric effort. The athlete's relative loads were then separated across four absolute load categories (120 – 129 kg, 140 – 149 kg, 160 – 169 kg, 180 – 189 kg). Barbell displacement was measured between three methods including a LT (GymAware, GymAware PowerTool Version 5, Kinetic, Canberra) attached 65 cm left of the barbell's centre (inside the barbell collar), 3D motion analysis tracking markers attached to the end of the barbell, and a cervical marker (C7), which was the criterion measurement. Results suggest the LT placement 65 cm left of barbell centre was highly valid ($r = 0.96 - 0.98$; $CV = 2.1 - 3.0\%$) compared to the criterion measurement location for the displacement data. The bias in displacement for the LT across the four load categories ranged from 0.9 – 1.5% compared to the C7 marker, whilst the markers on the end of the barbell, which were less valid ($r = 0.71 - 0.97$; $CV = 2.1 - 3.0\%$), had a bias of between 6.9 – 10.7% for displacement measurements compared to criterion displacement. Therefore, despite valid and reliable measures of displacement for both the LT and 3D motion analysis markers attached to the end of the barbell, slight overestimations of barbell displacement increase as the displacement measurement location moves to the ends of the barbell in heavy back squats.

Accelerometer-based Devices

Accelerometer-based devices have become popular in recent times because of the interest in wireless measurement tools to assess kinematic variables without impeding lifting performance, which may occur when using a tether-based LT. These wireless accelerometers assess velocity by calculating the integration of acceleration with respect to time [39]. They are relatively cheap, making them appealing to nonprofessional coaches and athletes. Research suggests that accelerometer-based devices are valid for assessing movement velocity in free-weight exercises

including the Smith machine bench press (MV), Smith machine back squat (MV and PV), free-weight barbell hip thrust (MV), dumbbell bicep curl (MV and PV) and Smith machine shoulder press (MV and PV) [35, 39]. Importantly, these previous studies assessing the validity of accelerometer-based devices to assess velocity combined all repetitions regardless of relative load for their validity analyses. Therefore, it is not known whether accelerometer-based devices are accurate across the entire relative load spectrum. This is important to discern since individuals lift with a variety of relative loads depending on the phase of training, and the accuracy of accelerometer-based devices to determine velocity may depend on the relative load lifted. Therefore, although accelerometer-based devices are relatively cheap, their ability to accurately determine velocity at across the entire relative load spectrum remains unclear.

Interestingly, many of the commercially available devices are categorised as a *wearable devices*, but recent research has found that an accelerometer-based device worn on the body is less accurate in assessing velocity (MV) than when attached to the barbell [35]. In addition to the reduced accuracy, the wearable aspect of these devices can also be problematic regarding the perceived cost benefit compared to LTs. For example, if a device is purchased and worn by each member of a large sporting team then the cost is similar to the investment of a LT. Therefore, even though some accelerometer-based devices are advertised as wearable devices, research suggests that accelerometer-based devices should be attached to the barbell to increase the accuracy of velocity monitoring and also reduce the cost of equipment for a team with many athletes.

VELOCITY-BASED 1RM PREDICTIONS

1RM – Velocity at 100%1RM ($1RM_{V1RM}$) Prediction Method

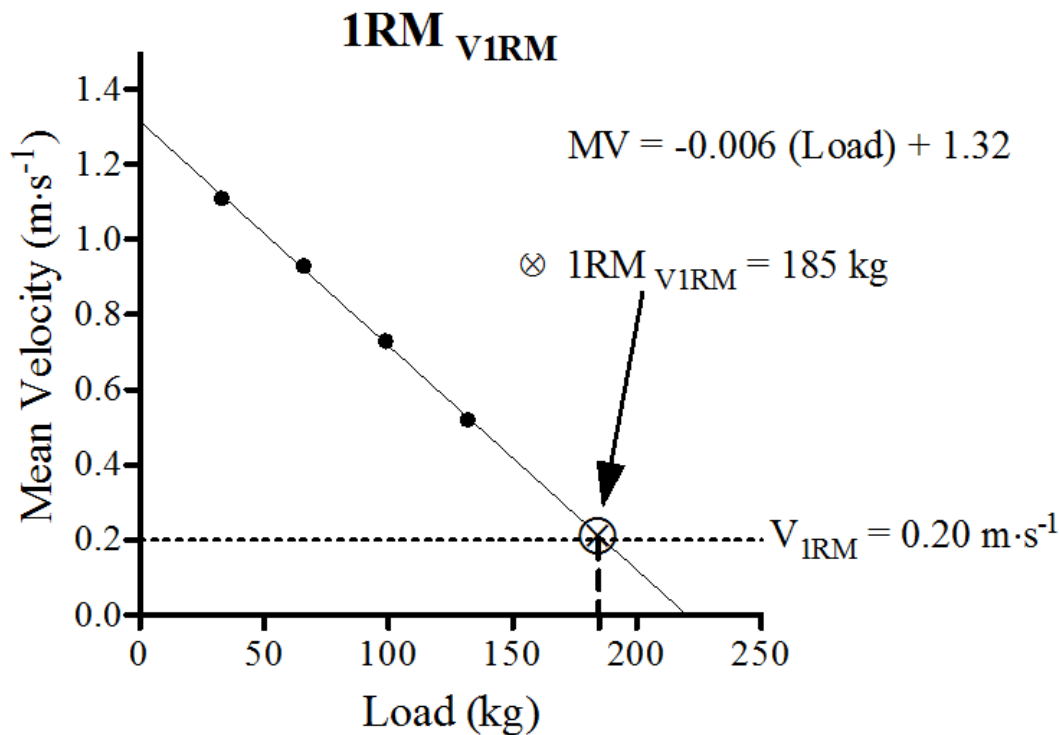


Figure 1. *1RM - Mean Velocity at 100%1RM ($1RM_{V1RM}$) Prediction Method*

The monitoring of movement velocity has enabled researchers to create novel methods to predict 1RM from submaximal loads for specific exercises. A major benefit of 1RM predictions from submaximal loads is that an individual can estimate maximal dynamic strength without having to lift maximal loads or perform submaximal repetitions to failure. A unique 1RM prediction-based approach is performed by extrapolating the load from the intersection of an individual's linear load-velocity regression line and the velocity at 1RM for that specific exercise (V_{1RM}) (Figure 1) [22]. Thus far, research has shown that the V_{1RM} -predicted 1RM method ($1RM_{V1RM}$) using MPV can be used to accurately estimate the actual 1RM for the free-weight bench press ($r = 0.99$; $CV = 0.82 - 1.48\%$), Smith machine bench press ($r = 0.99$; $CV = 0.86 - 1.37\%$) and Smith machine half-squat ($r = 0.98$; $CV = 0.38 - 0.75\%$) [40, 41]. Interestingly, the $1RM_{V1RM}$ prediction method for Smith machine exercises appears to be as accurate as repetition to failure 1RM prediction methods at loads $\leq 7RM - 10RM$ [42]. Contrastingly, recent work from Ruf et al. [43] found that although the $1RM_{V1RM}$ method was reliable ($ICC = 0.95 - 0.99$; $CV = 1.9 - 4.4\%$; standard error of the measurement [SEM] = 3.4 – 7.5 kg), it could not accurately predict daily

1RM ($r = 0.88 - 0.95$; $CV = 3.3 - 4.4\%$; $SEE = 9.1 - 13.7$ kg) in the free-weight deadlift exercise due to the unstable V_{1RM} ($ICC = 0.63$; $CV = 15.7\%$; $SEM = 0.03$ m·s⁻¹). Therefore, although it appears that the $1RM_{V_{1RM}}$ method may accurately predict the 1RM in Smith machine exercises, the same method could not predict 1RM in the free-weight deadlift. As the deadlift lacks a large eccentric component followed by a stretch reflex, it is possible that other free weight exercises may show different results. Therefore, it is important for researchers to determine if this method can accurately predict 1RM in other free-weight exercises such as the back squat.

1RM – Minimum Velocity Threshold ($1RM_{MVT}$) Prediction Method

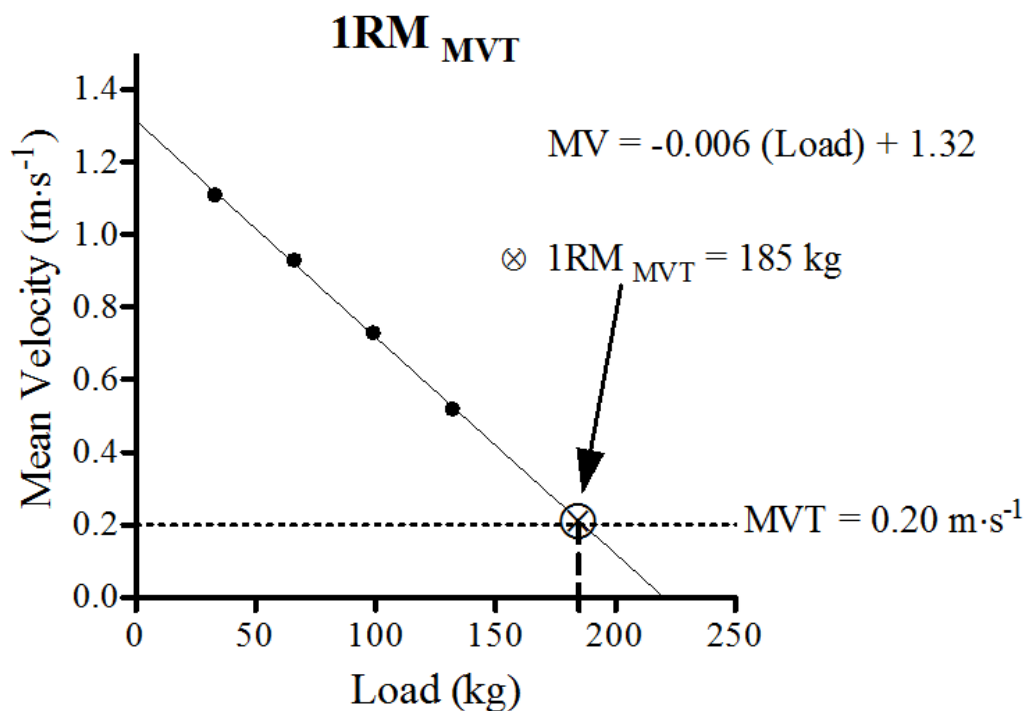


Figure 2. 1RM - Minimum velocity threshold ($1RM_{MVT}$) prediction method.

An alternative 1RM prediction method originated from the research from Izquierdo et al. [30] who had participants perform the Smith machine bench press and half-squat exercises. In that study, the authors suggested that the velocity obtained from the final repetition in a set to maximal voluntary concentric muscular failure and with different relative loads (60%, 65%, 70% and 75% 1RM) should be termed the minimum velocity threshold (MVT). Interestingly, the MVT at all relative loads assessed (60%, 65%, 70% and 75% 1RM) was similar to the V_{1RM} for both the bench press ($V_{1RM} = 0.15 \pm 0.03$ m·s⁻¹; 60% 1RM = 0.17 ± 0.04 m·s⁻¹; 65% 1RM = 0.18 ± 0.05

$\text{m}\cdot\text{s}^{-1}$; 70% 1RM = $0.18 \pm 0.05 \text{ m}\cdot\text{s}^{-1}$; 75% 1RM = $0.17 \pm 0.04 \text{ m}\cdot\text{s}^{-1}$) and half-squat exercises ($V_{1\text{RM}} = 0.27 \pm 0.02 \text{ m}\cdot\text{s}^{-1}$; 60% 1RM = $0.33 \pm 0.07 \text{ m}\cdot\text{s}^{-1}$; 65% 1RM = $0.31 \pm 0.06 \text{ m}\cdot\text{s}^{-1}$; 70% 1RM = $0.32 \pm 0.07 \text{ m}\cdot\text{s}^{-1}$; 75% 1RM = $0.31 \pm 0.05 \text{ m}\cdot\text{s}^{-1}$). In light of this, recent research investigated whether the MVT (velocity type: MPV and MV) for the free-weight deadlift exercise performed at 70% and 80% 1RM could be utilized in the linear regression equation of an individualised LVP to predict 1RM (Figure 2). Lake et al. [44] found the MVT was not accurate enough to predict the sessional 1RM for the deadlift (underestimated 1RM by 9–15%) because the MVT for the 70% 1RM ($0.28 \pm 0.11 \text{ m}\cdot\text{s}^{-1}$) and 80% 1RM ($0.32 \pm 0.12 \text{ m}\cdot\text{s}^{-1}$) sets to failure were significantly different to the MPV ($V_{1\text{RM}} = 0.16 \pm 0.05 \text{ m}\cdot\text{s}^{-1}$) and MV ($V_{1\text{RM}} = 0.17 \pm 0.05 \text{ m}\cdot\text{s}^{-1}$) at 1RM [44]. At present there are no studies investigating MVT-based 1RM predictions using the Smith machine, but based on the results of Lake et al. [44] it appears that this method should not be used to predict free-weight 1RMs.

1RM – Load at Zero Velocity (1RM_{LD0}) Prediction Method

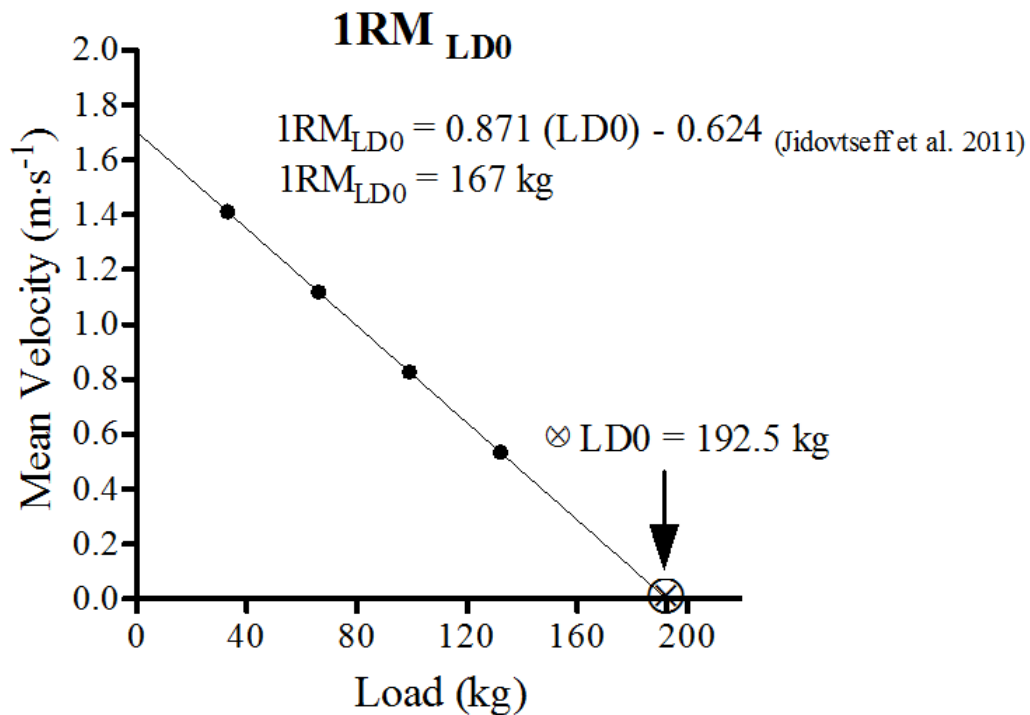


Figure 3. 1RM - Load at zero velocity (1RM_{LD0}) prediction method.

An alternative approach to using movement velocity for 1RM predictions is to extrapolate the load which corresponds to zero velocity (LD0) from the load-velocity relationship (Figure 3).

The data point at LD0 is an overestimation of 1RM but the magnitude of overestimation is believed to be reliable for an individual in a specific exercise. A predicted 1RM linear regression equation is then constructed from the relationship between LD0 and the actual 1RM ($1RM_{LD0}$). Jidovtseff et al. [23] showed that LD0 corresponded to $116 \pm 8\%$ of 1RM and was highly correlated ($r = 0.98$) to the actual 1RM in the Smith machine concentric only bench press exercise. The subsequent group mean regression equation derived from the participants LD0-actual 1RM relationship could predict the 1RM with moderate accuracy ($SEE = \sim 4.0$ kg or $\sim 7.0\%$). However, for the free-weight back squat, Hughes et al. [45] recently found the $1RM_{LD0}$ prediction method was moderately reliable ($ICC = 0.78 - 0.82$, $CV = 8.2 - 8.6\%$) but the predicted 1RMs were significantly different from the actual 1RM and when analysed using Bland-Altman plots the $1RM_{LD0}$ method exhibited a high degree of variability (bias = $-4.34 - -0.05$, 95% limits of agreement = $\pm 20.2 - 30.0$ kg). Based on these findings it is recommended the $1RM_{LD0}$ prediction method not be used to prescribe training loads. Although the $1RM_{LD0}$ prediction method seems promising in Smith machine exercises, the validity of this method to accurately predict 1RM in free-weight exercises appears to be flawed.

1RM – FV and LV Relationships ($1RM_{FV}$) Prediction Method

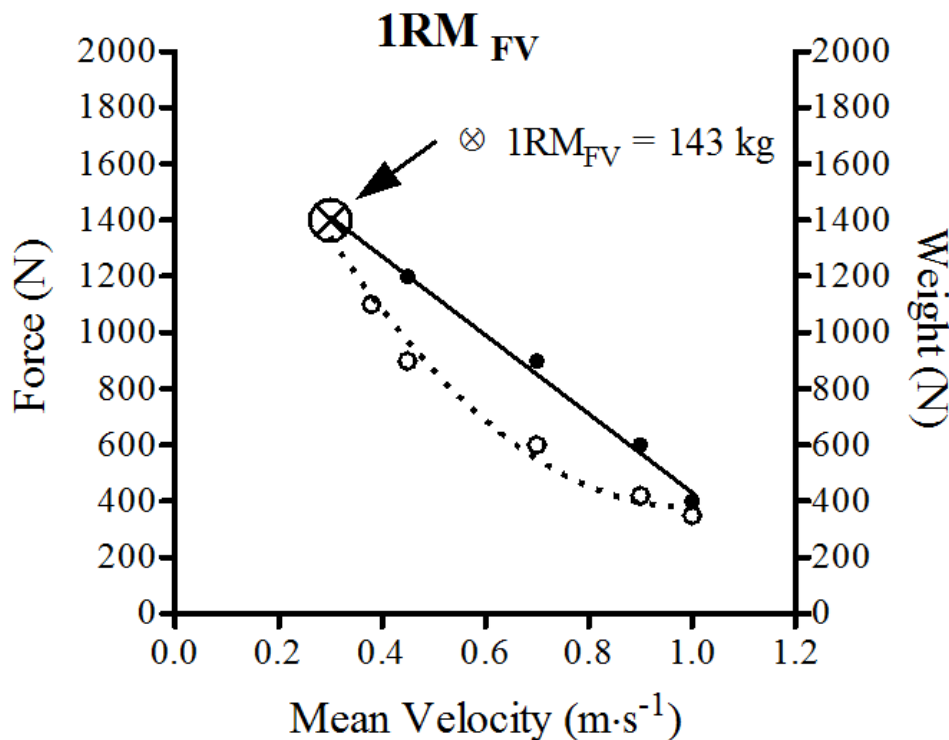


Figure 4. FV and LV relationships ($1RM_{FV}$) prediction method.

Another novel method to predict 1RM is based on the association between the force-velocity and load-velocity relationships. This method suggests the predicted 1RM is the heaviest load corresponding with the intersection of the regression lines of the load-velocity and force velocity relationship where the gravitational force an individual can produce is greater than the resisting weight (Figure 4). Picerno et al. [46] found that force-velocity/load-velocity 1RM predictions ($1RM_{FV}$) almost perfectly correlated with the actual 1RM for the machine chest press and leg press exercises ($r = 0.99$). Bland-Altman and SEE analyses also demonstrated high validity (chest press: bias = -1.32 kg, 95% limits of agreement = -3.58 – 0.94 kg, SEE = 1.2 kg; leg press: bias = -1.76 kg, 95% limits of agreement = -5.81 – 2.29 kg, SEE = 2.1 kg). While this 1RM prediction method appears to be a valid alternative to other 1RM prediction methods in machine weight exercises, research has found this may not be the case in free-weight exercises. Hughes et al. [45] found the reliability (ICC = -0.28 – 0.00) and validity (bias = -110.83 – 9.88, 95% limits of agreement = ± 152.7 – 317.5 kg) were extremely poor. The authors suggested the overestimations of $1RM_{FV}$ predictions of 1RM were attributed to faster than expected velocities with low loads (20% – 40% 1RM), whilst the underestimations of maximal strength were caused by excessively slow velocities with heavy loads (80% – 90% 1RM). Therefore, the $1RM_{FV}$ prediction method may be

valid for predicting maximal strength in machine weight exercises but its accuracy for predicting the 1RM in the free-weight back squat exercise is not advised.

1RM – Body weight 1RM ($1RM_{BW}$) prediction method

A limitation of previous 1RM prediction methods is that they require multiple training or warm-up sets to estimate 1RM. A more rapid and less demanding method of 1RM prediction has recently been proposed for Smith machine concentric only half-squats (90° knee angle), where a multiple linear regression equation can predict 1RM from just a single set of three repetitions performed with a load equal to body weight ($1RM_{BW}$) [47]. The $1RM_{BW}$ prediction equation ($1RM = -61.93 + [121.92 \cdot MV] + [1.74 \cdot \text{load}]$) requires only two variables, the load of the set equal to the individual's bodyweight (in kilograms) and the MV ($\text{m} \cdot \text{s}^{-1}$) of the fastest repetition in the set. Bazuelo-Ruiz et al. [47] reported that for 105 untrained participants, the $1RM_{BW}$ prediction method had very high validity ($ICC = 0.79$) but significantly underestimated ($p < 0.001$) the actual 1RM by an average error of 17.9 kg ($0.25 \text{ kg} \cdot \text{kg}^{-1}$). In support of this, previous research has demonstrated that 1RM prediction methods should incorporate loads closer to 100% 1RM to ensure accuracy [48]; therefore, the magnitude of error reported by Bazuelo-Ruiz et al. [47] is likely due to the creation of the multiple linear regression equation from a relative load corresponding to only 52.1% 1RM. Despite this, the current $1RM_{BW}$ prediction method appears to lack the accuracy required to monitor and adjust sessional training loads for well-trained athletes. In addition, group mean equations developed from untrained individuals may not be applicable for strength-trained athletes.

RELIABILITY OF DIFFERENT VELOCITY MEASURES

To truly understand which type of velocity should be used to monitor individuals for specific exercises, the reliability of the three types of concentric velocity must be established. Recent research has compared the reliability of PV, MV and MPV for the Smith machine eccentric-concentric bench throw and concentric only bench throw exercises [49]. Garcia- Ramos et al. [49] found that PV, MV and MPV were all highly reliable for both types of bench throw variations from 20 – 90% 1RM ($CV = 1.7 – 7.4\%$) but not at 100% 1RM ($CV = 13.2 – 23.5\%$). Notably, PV appeared to be the most reliable velocity measurement and was significantly more reliable than MPV for both bench throw variations at all relative loads examined (20 – 100% 1RM). Interestingly, even though previous research has suggested that it may be more valid and

appropriate to monitor MPV than MV at light and medium loads [32], the results of Garcia- Ramos et al. [49] suggest that MV was significantly more reliable than MPV at light and medium loads for the eccentric-concentric bench throw (20 – 50% 1RM) and the concentric only bench throw (20 – 50% 1RM). However, even though MPV was found to be the least reliable of the different types of concentric velocity in the Smith machine bench throw, MPV was still reliable which suggests it may not matter which type of concentric velocity is used for monitoring purposes.

Another recent study investigated the reliability of MPV in the Smith machine concentric-only seated military press exercise. Balsalobre-Fernández et al. [50] found an almost perfect linear relationship ($R^2 = 0.987$; $SEE = 0.04 \pm 0.02 \text{ m}\cdot\text{s}^{-1}$) existed between load and MPV, but MPV was relatively unstable ($CV = 12.9 - 24.6\%$) at relative loads from 30 – 100% 1RM. This suggests that the use of tracking MPV in the Smith machine concentric-only seated military press exercise is questionable, but further research is required to determine if MPV as well as PV and MV are reliable in other exercises. Given the scarcity of comparable literature between Smith machine and free-weight resistance training exercises, it is difficult to provide a conclusive consensus on which velocity measure should be used during VBT.

LOAD-VELOCITY PROFILES (LVP)

Many studies have established that when an individual exerts maximal concentric effort with a consistent range of motion, an almost perfect inverse linear relationship exists between load and velocity in a variety of exercises including the Smith machine half squat [51, 52], Smith machine concentric only half squat [52], Smith machine full squat [51], Smith machine countermovement jump [52], Smith machine squat jump [52], Smith machine bench press [23, 31, 32, 53], Smith machine bench press throw [49], Smith machine prone bench pull [53], Smith machine military press [50], free-weight deadlift [44], and pull up [54]. Several studies investigating the load-velocity relationships have provided group mean equations for each exercise [23, 31, 51], but more recent research recommends that individualised load-velocity relationships should be created since individuals produce unique movement velocities based on factors associated with their limb biomechanics and fibre type expression [49, 50, 55]. The results and recommendations from this research has encouraged strength and conditioning coaches to profile their athletes for each exercise by creating individualised LVPs. This is practically useful since it is hypothesised that when an athlete is fatigued, they may perform repetitions with reduced movement velocity compared to their LVP that was established in a non-fatigued state. On the other hand, if an

individual has increased their maximal strength, their movement velocity is believed to also increase with the same absolute load according to the load-velocity relationship. However, there is a paucity of evidence reporting the reliability of movement velocity and the typical error observed between training sessions. This is important to quantify so that training decisions based on changes in movement velocity can be made with a certain level of accuracy.

Research by Gonzalez-Badillo et al. [31] investigated the stability of MPV at baseline and following six weeks of upper body resistance training with the same relative loads (at 5% incremental loads between 30% and 100% 1RM). Notably, the test/re-test reliability of MPV at baseline was not reported, so the typical variation in MPV between sessions is not known. However, despite an average improvement of 9.3% in maximal strength, there was no statistically significant change in MPV across the relative load spectrum (ICC = 0.81 - 0.91; CV = 0.0 - 3.6%) including the velocity at 100% 1RM (V_{1RM}). This suggests that even when maximal strength changes, the MPV remains stable at the same relative load according to the LVP. Therefore, MPV can be measured to monitor and prescribe relative load. Importantly, no study has verified whether movement velocity remains stable at the same relative load when maximal strength changes following a training intervention for a free-weight lower body exercise.

García-Ramos et al. [49] examined the reliability of PV, MPV and MV in the eccentric-concentric and concentric only bench press throw exercises performed on a Smith machine. Thirty participants performed four 1RM sessions, twice a week, at least 48-hours apart, with two sessions of the same bench press throw variant performed within the same week. Interestingly, they determined that PV, MPV and MV were all reliable at relative loads from 20% to 90% 1RM in 5% incremental loads but V_{1RM} was unreliable with all concentric movement velocity types. PV was found to be more reliable between sessions than MV and MPV. However, it was determined that MV was the most appropriate velocity variable for creating individualised LVPs and monitoring training since it was reliable and provided the most linear load-velocity relationship for both the eccentric-concentric and concentric only bench press throw exercises. Similarly, Pestaña-Melero et al. [55] found PV, MPV and MV were all reliable at relative loads from 20% to 90% 1RM (in 5% incremental loads) except for V_{1RM} in the eccentric-concentric and concentric only bench press performed on a Smith machine. Despite these promising findings, no studies have examined the reliability of PV, MPV and MV in a commonly utilized lower body free-weight exercise such as the squat. Furthermore, no research has looked at using individualised LVPs to modify training load. Research should investigate the efficacy of such training strategies to account for individual differences in the rate of training adaptation, since the LVP-based VBT

method could be a practical and valid strategy to adjust training load according to the velocity of repetitions performed in the warm-up and comparing with the individuals LVP.

VELOCITY LOSS THRESHOLDS

One of the more common approaches to VBT allows the magnitude of velocity loss during training to dictate the end of a working set. If a pre-determined velocity loss threshold is established, the termination of that set can occur when the velocity of the concentric portion of the lift falls short of the threshold [21]. Since faster movement velocities with a given load increase the neuromuscular stimuli and adaptations to strength training [14], decreases in movement velocity can be detrimental. Furthermore, training to concentric muscular failure can be unfavourable for maximising gains in strength and power output, particularly in well-trained athletes who are likely candidates for adopting VBT [12, 13]. Therefore, if the training target is to optimise maximal strength and power development, one can monitor the barbell velocity and implement velocity loss thresholds to avoid performing repetitions at or close to concentric muscular failure.

Two variations of the velocity loss threshold method have been introduced [21]. The variable sets velocity loss threshold (VS_{VL}) method includes a fixed training load and total number of repetitions, but allows for an indefinite number of sets, each finishing when a repetition velocity drops below a pre-determined maximum percent velocity loss [33]. This method allows an athlete to complete as many high velocity repetitions in as few sets as possible, which allows for flexibility in determining the optimal repetition scheme to accommodate daily fluctuations in performance. For example, if an athlete is able to maintain high velocity outputs that do not go below the velocity loss threshold, then the strength session could theoretically be completed in a shorter period of time. Contrastingly, if an athlete is unable to maintain high velocity repetitions above the acceptable velocity loss threshold then they are afforded more sets and total recovery time to complete the total number of prescribed repetitions.

Pérez-Castilla et al. [33] employed the VS_{VL} method in the loaded Smith machine countermovement jump (CMJ) exercise over a four-week training period. The target MPV ($1.20 \text{ m}\cdot\text{s}^{-1}$ equating to $\sim 40\%$ 1RM) and total repetitions (36-repetitions) were matched between groups with the only difference pertaining to the allowed velocity loss threshold during each set of the CMJ (10% vs. 20%). Over the entire training study, participants who performed sessions with a 10% MPV loss threshold performed repetitions with significantly higher velocities than the 20%

MPV loss group yet had comparable increases in CMJ-1RM and similar decreases in 15m sprint times. However, it should be stated that all participants in this study also performed three additional lower body dominant exercises in the same sessions which were performed in the same manner between groups and did not comply with the VS_{VL} method (matched for load, sets, repetitions, load etc.). Therefore, the true training effect of the different velocity loss configurations for the CMJ was likely to have been neutralised. Consequently, future studies should look to examine the effects of just the VS_{VL} method.

An alternative strategy to the VS_{VL} method is the fixed sets velocity loss threshold (FS_{VL}) method. This requires a coach to predetermine an athletes training load and number of sets but has them perform repetitions in a set until they are no longer able to produce the required velocity. Pareja-Blanco et al. [20] found that participants who trained for eight weeks with high relative loads (~68% to ~85% 1RM) in the Smith machine back squat exercise using a 20% velocity loss threshold trained with approximately 40% fewer repetitions (total repetitions: 185.9 ± 22.2 vs. 310.5 ± 42.0) and faster movement velocities for the training repetitions (MV: $0.69 \pm 0.02 \text{ m}\cdot\text{s}^{-1}$ vs. $0.58 \pm 0.03 \text{ m}\cdot\text{s}^{-1}$) compared to a 40% velocity loss threshold group, yet had similar improvements in maximal strength ($p>0.05$, 18.0% vs. 13.4%) and significantly greater increases in CMJ height (9.5% vs. 3.5%). Based on the findings of Pareja-Blanco et al. [20], it appears that a 20% velocity loss threshold for the squat performed with high relative loads is effective for strength and power development.

Another study by Pareja-Blanco et al. [26] had 16 resistance-trained professional male soccer players perform six weeks (18 sessions, ranging from ~50 to ~70% 1RM) of Smith machine back squat training and were evenly assigned into two groups, which differed by a 15% or 30% velocity loss threshold in each training set. Subsequently, the 15% velocity loss group trained with significantly fewer repetitions (total repetitions: 251.2 ± 55.4 vs. 414.6 ± 124.9 ; mean repetitions/set: 6.0 ± 0.9 vs. 10.5 ± 1.9) and at faster movement velocities (MV: $0.91 \pm 0.01 \text{ m}\cdot\text{s}^{-1}$ vs. $0.84 \pm 0.02 \text{ m}\cdot\text{s}^{-1}$), yet had significantly greater increases in maximal strength (estimated 1RM squat) and power output (CMJ height) compared to the 30% velocity loss group. However, significantly greater hypertrophy was observed in the 30% velocity loss group, which demonstrates that smaller velocity loss thresholds may be suitable for enhancing maximal strength and power development, but the reduced resistance training volume may be detrimental to hypertrophic gains. The aforementioned velocity loss threshold research has merit for individualised training load prescription but notably, these studies had their participants perform exercises on a Smith machine and not in a large mass free-weight barbell exercise. This is

important to discern since free-weight exercises often require movements in both the vertical and horizontal planes and are extensively utilised in practice with most athletes.

SUMMARY OF LITERATURE REVIEW

In summary, this chapter consisted of five main sections. Firstly, it reviewed the advantages and limitations of velocity measuring devices related to VBT, outlining the need to verify practical devices that can accurately measure velocity but also provide immediate feedback so that training decisions (termination of a set or training load modification) can be made rapidly. The second main section discussed the myriad of 1RM prediction methods and their limitations regarding accuracy. The $1RM_{V1RM}$ appeared to be the most accurate method for predicting maximal strength but there is a dearth of research examining such prediction methods in free-weight exercises. Research investigating the reliability of PV, MPV, and MV is discussed in section three. These three concentric velocities are often used to develop LVPs, but research is scarce and inconclusive with only upper body Smith machine exercises currently investigated. Furthermore, there is a paucity of evidence reporting the typical variation in velocity between training sessions. The reliability and typical variation in velocity should be ascertained so that strength and conditioning coaches can make training decisions with some degree of accuracy based on meaningful changes in velocity. In addition, the reliable velocities and their corresponding relative loads can be incorporated into LVPs with the potential to be used as a training method to adjust load, which is discussed in section four. Lastly the final section discussed the logic and application of velocity loss threshold research to manipulate training volume (number of repetitions per set) for the enhancement of strength and power. However, no study has investigated VBT methods for modifying training load based on when training volume is matched.

CHAPTER 3: STUDY 1

VALIDITY OF VARIOUS METHODS FOR DETERMINING VELOCITY, FORCE AND POWER IN THE BACK SQUAT

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ABSTRACT

Purpose: This investigation examined the validity of two kinematic systems for assessing MV, PV, mean force (MF), peak force (PF), mean power (MP), and peak power (PP) during the full depth free-weight back squat performed with maximal concentric effort. **Methods:** Ten strength-trained men (26.1 ± 3.0 y; 1.81 ± 0.07 m; 82.0 ± 10.6 kg) performed three 1RM trials on three separate days, encompassing lifts performed at six relative intensities including 20%, 40%, 60%, 80%, 90%, and 100% 1RM. Each repetition was simultaneously recorded by a PUSH band, commercial LT (GymAware [GYM]), and compared with measurements collected by a laboratory based testing device consisting of four LTs and a force plate. **Results:** Trials 2 and 3 were used for validity analyses, combining all 120 repetitions indicated the GYM was highly valid for assessing all criterion variables while the PUSH was only highly valid for estimations of PF ($r = 0.94$; CV = 5.4%; ES = 0.28; SEE = 135.5 N). At each relative intensity, the GYM was highly valid for assessing all criterion variables except for PP at 20% (ES = 0.81) and 40% (ES = 0.67) of 1RM. Moreover, the PUSH was only able to accurately estimate PF across all relative intensities ($r = 0.92 - 0.98$; CV = 4.0 – 8.3%; ES = 0.04 – 0.26; SEE = 79.8 – 213.1 N). **Conclusions:** The PUSH accuracy for determining MV, PV, MF, MP, and PP across all six relative intensities was questionable for the back squat, yet the GYM was highly valid at assessing all criterion variables, with some caution given to estimations of MP and PP performed at lighter loads.

INTRODUCTION

Assessments of velocity, force and power are often employed to monitor training induced adaptations [31, 56, 57]. For elite athletes, changes in these measures can be minor, yet significant. As a consequence, equipment used to monitor changes in performance should be precise. In a laboratory based environment, LTs are often used to accurately measure velocity, force plates ascertain ground reactions forces, and a combination of LTs and force plates can be employed to estimate power output [37, 58-60]. Importantly, laboratory based testing is considered the “gold standard” for data collection, yet is limited due to the large expense, transportation difficulties, and practical complications that can arise from testing with large groups of team sport athletes. Consequently, several field based devices including portable LTs, accelerometers, and inertial sensors (combination of accelerometer and gyroscope) have been invented to overcome these limitations [36, 61-63]. However, it is important to determine the devices accuracy to ensure that training decisions are not made as a result of device measurement error.

One LT device scientifically determined to accurately assess kinematic variables is the GymAware [37, 60, 64]. This portable field based device is a popular tool used to monitor and test athletes. However, it may be cost prohibitive for non-professional sporting teams thus limiting its use by coaches and athletes. Furthermore, since it requires the use of a cable/wire attachment to the barbell, it can be limited in the number of lifting exercises that it can effectively quantify. Consequently, there has been an increased interest in wireless measurement tools to assess kinematic variables without impeding lifting performance due to direct attachments.

Recently, a wearable inertia sensor (PUSH) has been developed to measure velocity during resistance training exercises. In addition, it has been suggested that force and power can be accurately estimated from the determined velocity of movement. Presently, only two studies have validated the PUSH with one study employing a Smith machine exercise [39], while the other investigated dumbbell exercises [65]. Interestingly, both studies suggested the PUSH accurately measured both mean and peak velocity. However, no previous study has examined the validity of the PUSH with the use of a large mass free-weight exercise, such as the back squat, across a variety of training intensities. Importantly, the PUSH is relatively inexpensive compared to the GYM but since many sporting teams already possess GYM technology, evaluating the accuracy of measurement devices such as the PUSH is highly beneficial. Therefore, the purpose of this study was to investigate the ability of two field-based devices to accurately measure velocity, force and power in the back squat exercise compared to laboratory based testing equipment.

METHODS

Participants

Ten male resistance-trained volunteers took part in this study (26.1 ± 3.0 y; 1.81 ± 0.07 m; 82.0 ± 10.6 kg). All participants could perform the full back squat with at least 1.5 times their body mass, had at least 6 months of resistance training experience, and were injury free. The participant's average 1RM back squat and 1RM to body mass ratio were 142.1 ± 33.8 kg and 1.72 ± 0.23 kg, respectively. All participants provided written informed consent prior to participation in the present study in accordance with the ethical requirements of Edith Cowan University Human Research Ethics Committee and the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Study Design

This study assessed the validity of the PUSH and GYM devices in order to determine the accuracy of MV, PV, mean force (MF), peak force (PF), mean power (MP) and peak power (PP) during two incremental back squat 1RM assessments compared to a laboratory based testing (LAB) device (i.e. 4 LTs and force plate). All participants performed an initial 1RM assessment (trial 1) followed by two further 1RM trials (trials 2 and 3) with each trial separated by 48 hours. The initial 1RM assessment was done so that accurate relative 1RM loads could be lifted in the remaining two 1RM sessions. Consequently, the field and laboratory devices were only used to measure the criterion variables during trials 2 and 3.

Testing Procedure

One-Repetition Maximum (1RM) Assessment

1RM assessments were performed in a power cage (Fitness Technology, Adelaide, Australia) using a 20 kg barbell (Eleiko®; Halmstad, Sweden). The warm-up and procedures were identical in all 1RM assessments with participants commencing the session by pedalling on a cycle ergometer (Monark 828E cycle ergometer; Vansbro, Dalarna, Sweden) for five minutes at 100 W and 60 revolutions per minute, performing three minutes of dynamic stretching, followed by a back squat protocol consisting of three repetitions at 20%, 40%, and 60% 1RM, and 1-repetition at 80%, 90%, and 100% 1RM. These relative loads were estimated for session 1. Reliability of this method to determine 1RM has been previously established (ICC = 0.99; CV = 2.1%; SEM = 2.9 kg; effect size [ES] = 0.03) [66]. Following successful 1RM attempts, the weight was increased between 0.5 and 2.5 kg until no further weight could be lifted, with a maximum of five 1RM

attempts given. Participants were instructed to apply constant downward pressure on the barbell and to keep their feet in contact with the floor for the entirety of the repetition. Passive recovery time between warm-up sets was two minutes while three minutes rest period was given between 1RM attempts. For each back squat repetition, the eccentric phase was performed in a controlled manner at a self-selected velocity until full knee flexion was achieved whereas the concentric phase was completed as fast and impulsively as possible with the aid of verbal encouragement. Peak knee flexion angle at the bottom of the squat ($123.1 \pm 11.2^\circ$) was measured in trial 1 using a goniometer. This knee angle at the bottom of the squat corresponded to a specific barbell depth recorded on a LabView analysis program. The recorded barbell depth at full knee flexion was then monitored by visual displacement curves on the LabView analysis program to ensure the same barbell depth was maintained for each repetition in all trials [66, 67].

Data Acquisition

For trials 2 and 3, each repetition was simultaneously measured using the PUSH, GYM and LAB methods. The PUSH was worn on the right forearm immediately inferior to the elbow crease with the on/off button located proximally (as suggested by the manufacturer) [39, 65]. Data obtained from the PUSH were recorded at a sampling rate of 200 Hz via Bluetooth™ connection with a smartphone (iPhone, Apple Inc., California, USA) using a proprietary application [39, 65]. In contrast, the GYM data were transmitted via Bluetooth™ to a tablet (iPad, Apple Inc., California, USA). The GYM recorded the displacement time curve data by determining changes in the barbell position. The device sampled and time stamped the changes in barbell position at 20 ms time points [68], which was down sampled to 50 Hz for analysis [60]. Velocity and acceleration data were then calculated from the first and second derivate of the change in barbell position with respect to time. Force values were determined from the system mass multiplied by the acceleration data, where system mass was the barbell load plus the relevant body mass of the participant. Power values were evaluated from the product of the force and velocity curve data. Comparatively, the PUSH determined velocity by measuring the linear accelerations and angular velocities of the movement where vertical velocity was calculated by the integration of acceleration with respect to time [39]. Similar to the GYM, force estimations by the PUSH were calculated from the system mass multiplied by the acceleration data whereas power values were determined from the product of the force and velocity curve data.

For the LAB system, all kinetic and kinematic data were collected using similar methodology to previous research [66, 67, 69]. Briefly, velocity measures were captured from four

LTs (Celesco PT5A-250; Chatsworth, California, USA) that were mounted to the top of the squat rack with two positioned in an anterior and posterior location on both the left and right side of the barbell [67]. The utilization of four LTs allowed for the quantification of both vertical and horizontal movements for both sides of the barbell and establishes a more accurate “central displacement” position [67]. Both MF and PF were obtained directly from the quantification of ground reaction forces with the use of a force plate (AMTI BP6001200, Watertown, Massachusetts, USA). Power measures were calculated from the product of the direct measurement of ground reaction force and bar velocity [67, 70]. The LT and force plate data were collected through a BNC-2090 interface box with an analogue-to-digital card (NI-6014; National Instruments, Austin, Texas, USA) and sampled at 1000 Hz. All data were collected and analysed using a customised LabVIEW program (National Instruments, Version 14.0). All signals were filtered with a 4th order-low pass Butterworth filter with a cut-off frequency of 50 Hz. The total tension on the barbell as a result of the transducer attachments was 17.25 N in a superior direction, which was accounted for in all calculations.

Values of MV, MF, and MP obtained by the PUSH, GYM and LAB, were determined as the average of the data collected during the concentric phase of the movement (greatest descent to standing position), whereas PV, PF, and PP were determined as the maximum value in the same concentric period. From trials 2 and 3, only one repetition (fastest average concentric velocity determined from LAB data) was selected from each of the sets performed at 20%, 40%, and 60% 1RM to ensure an equal number of repetitions were used for the validity analyses from each relative intensity.

Statistical Analyses

Validity analyses of the GYM and PUSH were determined by 1) combining all 120 repetitions performed by each individual regardless of relative load, and 2) examining the devices at each relative intensity (20%, 40%, 60%, 80%, 90%, and 100% 1RM). The validity of the field-based devices was determined from the magnitude of the Pearson product moment correlation (r), CV, and the ES. For this study, the field based devices were deemed highly valid if they met the three following criteria: very high correlation (>0.70) [71], moderate CV ($\leq 10\%$) [72, 73], and a trivial or small ES (<0.60) based on the Hopkins modified Cohen scale (<0.20 , trivial; 0.2 - 0.6, small; 0.6 - 1.2, moderate; 1.2 - 2.0, large; 2.0 - 4.0, very large; >4.0 , extremely large) [74, 75]. The SEE was also determined [75]. Confidence limits for all validity analyses were set at 95%. Systematic bias between LAB and field based methods for each criterion measure was assessed

using a repeated measures analysis of variance (ANOVA) with correction for sphericity and a type-I error rate set at $\alpha < 0.05$ (IBM SPSS version 22.0, Armonk, New York, USA). Tukey post hoc comparisons were utilized when appropriate. Data are reported as mean \pm SD unless stated otherwise.

RESULTS

Average values of mean and peak velocity, force and power at each relative load are displayed in Figure 5. Systematic bias was evident for PUSH estimations of MF and PP, and GYM estimates of PF and PP (Figure 5). When all 120 repetitions were combined, the PUSH was highly valid for estimations of PF only (Figure 6). By comparison, the GYM was highly valid for all criterion variables.

When the data were analysed at the six relative intensities, the GYM was highly valid across all relative loads for values of MV, PV, MF, and PF (Figures 7 – 10). However, MP and PP values estimated by the GYM were not highly valid at 20 and 40% of 1RM due to the moderate ES (Figure 11C & 12C). The PUSH was highly valid at all relative intensities for estimations of PF only (Figure 10). More specifically, the PUSH did not meet our criteria of high validity for estimations of MV at greater than or equal to 80% of 1RM (Figure 7); PV above 20% of 1RM (Figure 8); MF at or below 90% of 1RM (Figure 9); MP at 40% of 1RM and above (Figure 11); and PP at all relative intensities (Figure 12).

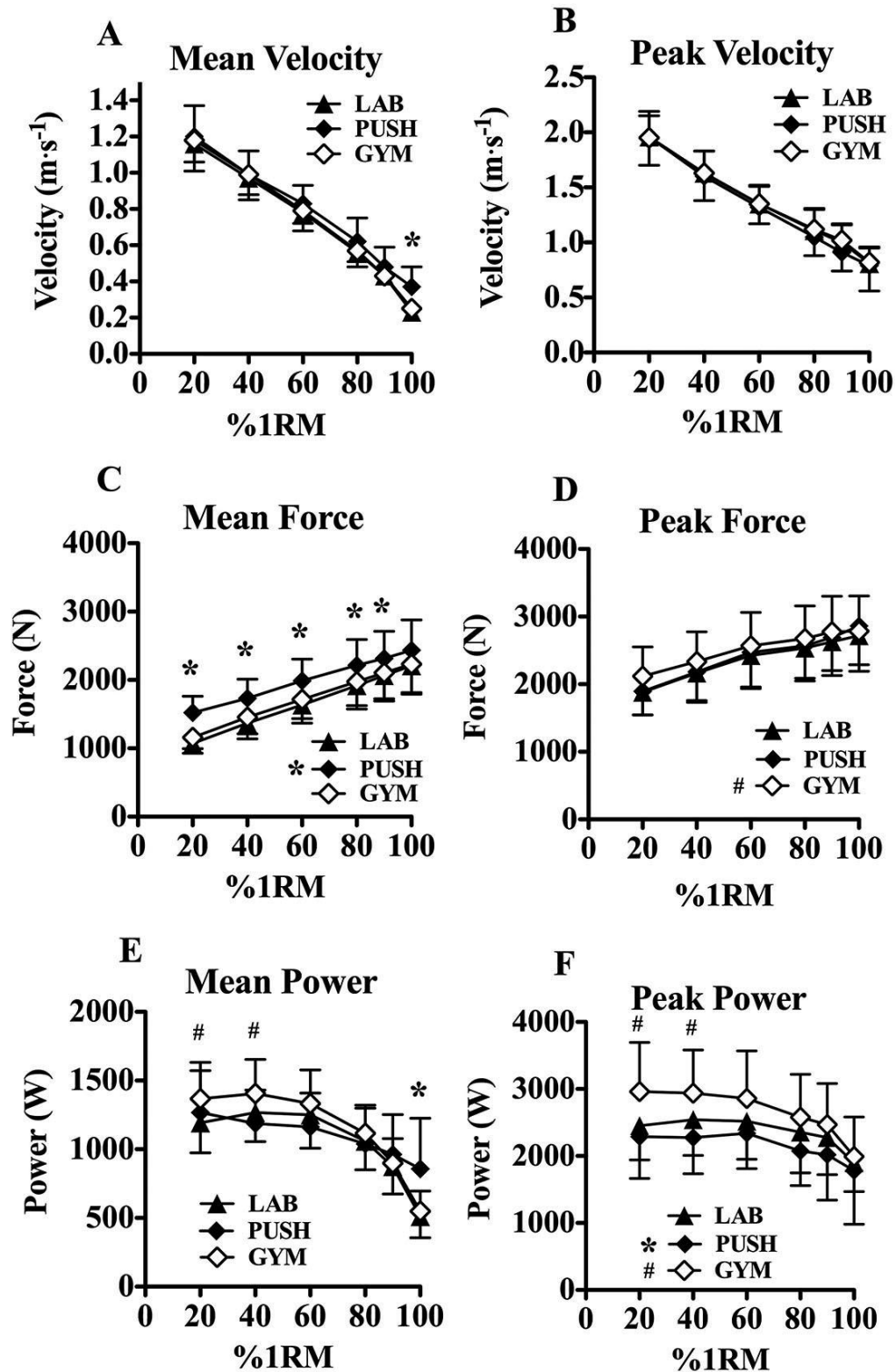


Figure 5. Mean and peak values of velocity, force, and power. Abbreviation: 1RM, 1-repetition maximum. *Significant differences between PUSH and Laboratory methods. #Significant differences between GymAware and Laboratory methods.

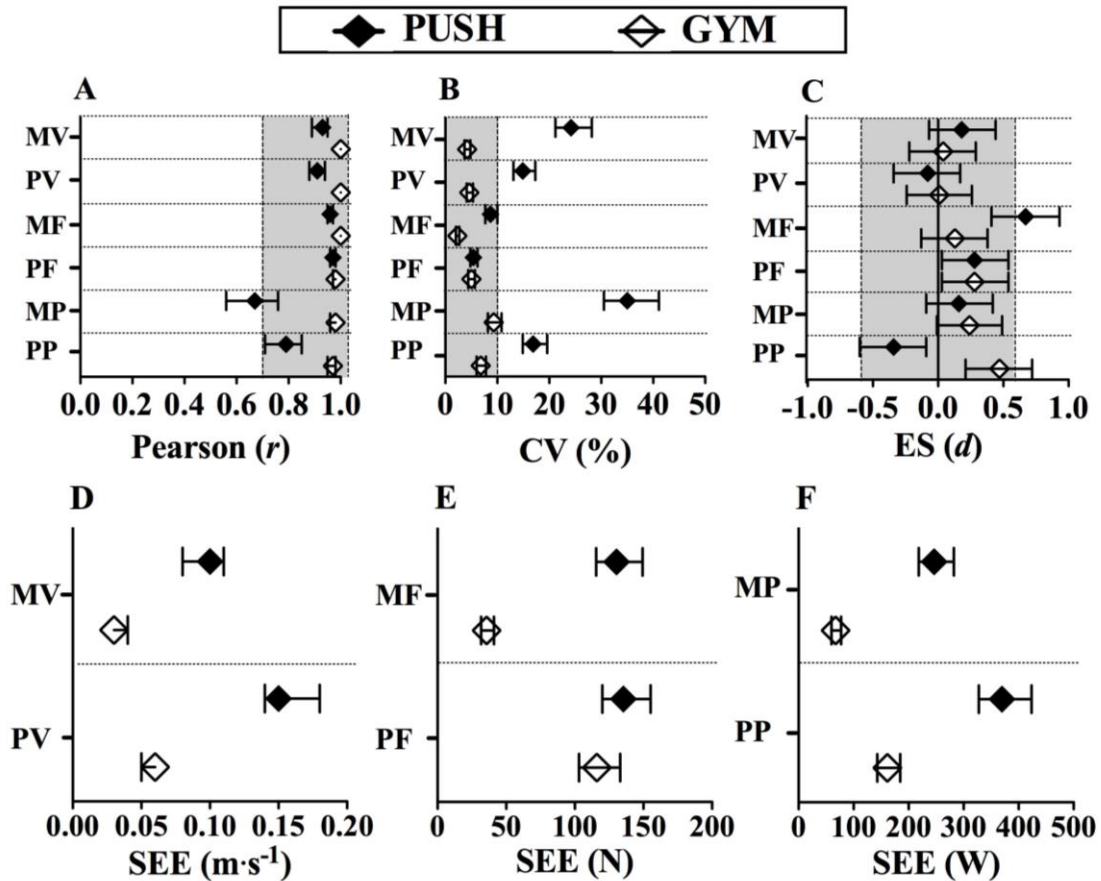


Figure 6. Validity of the PUSH and GymAware for the measurement of mean velocity (MV), peak velocity (PV), mean force (MF), peak force (PF), mean power (MP), and peak power (PP). Forest plots displaying (A) Pearson correlation coefficient, (B) coefficient of variation, (C) effect-size estimates, and standard error of the estimate for (D) MY and PV, (E) MF and PF, and (F) MP and PP.

DISCUSSION

The aim of this study was to assess the validity of two field based devices to accurately determine mean and peak values of velocity, force and power in the back squat exercise. When all repetitions were combined for analyses regardless of the relative load, the GYM was valid in the assessment of all criterion variables yet the PUSH only accurately estimated PF. Although this information is helpful and allows us to compare our results with previous findings [39, 65], it is important to understand the accuracy of field based devices at a variety of relative intensities since most athletes will perform resistance-training exercises with varying loads depending on the phase of the periodized training plan. Thus, when the data were analysed for each relative load, the GYM accurately estimated all criterion variables except for PP, which was invalid at lighter loads, more specifically, at 20% and 40% 1RM in the back squat exercise. By comparison, the PUSH was only

able to accurately estimate MV across all relative intensities. Moreover, MV, PV, MF, MP, and PP quantified by the PUSH across all six relative loads were questionable.

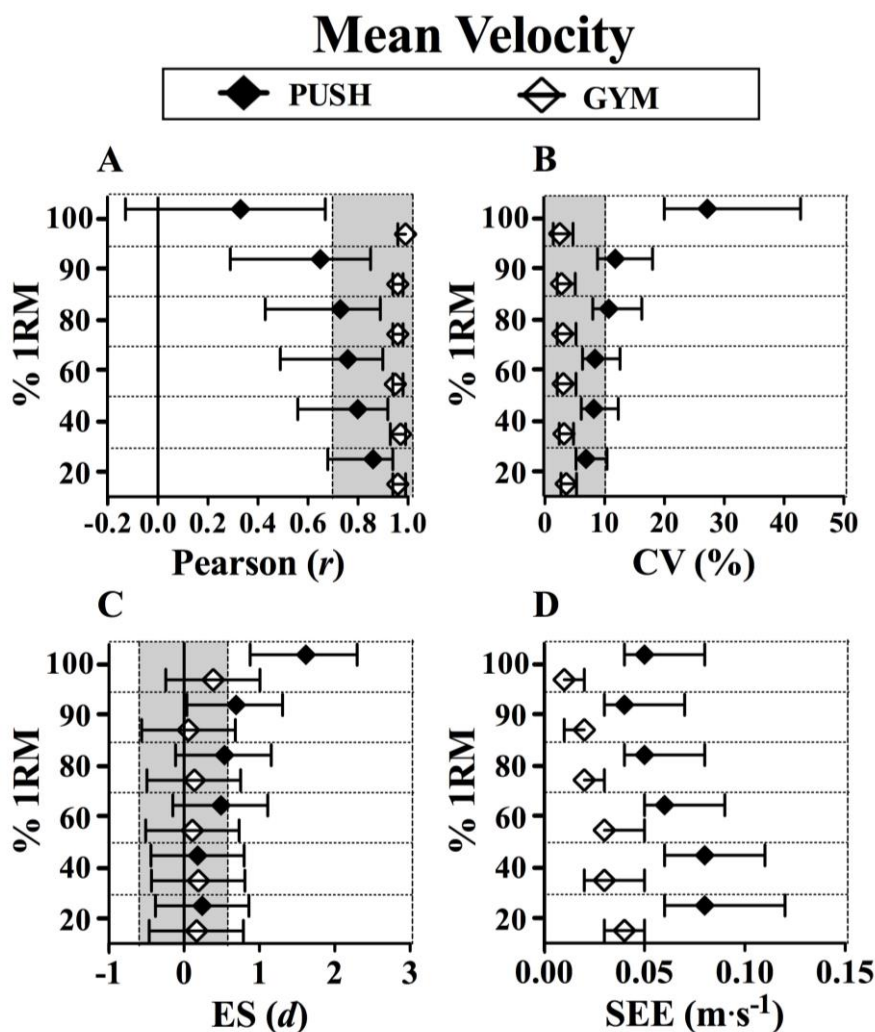


Figure 7. Validity of mean velocity in the back squat for the PUSH and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1-repetition maximum (1RM) compared with Laboratory methods. Forest plots displaying (A) Pearson correlation coefficient, (B) coefficient of variation, (C) effect-size estimates, and (D) standard error of the estimate. Abbreviation: 1RM, 1-repetition maximum. Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.

For measurements of MV, the PUSH was less valid at heavier loads when compared to LAB results. Specifically, the greatest lack of validity was seen at loads equal to and above 80% 1RM, which is problematic for athletes using the device when training with higher intensities when targeting maximal strength development. Despite this shortcoming, the PUSH band met the validity criteria in the measurement of MV at light and moderate loads (<60% 1RM). Interestingly, for measurements of PV the PUSH was only valid at the lightest load tested (20% 1RM). Based

on the results of this study, we would suggest the PUSH can accurately measure MV at light and moderate relative loads, typically used in the back squat during power based training programs, but is questionable for measurements of PV across the relative intensity spectrum.

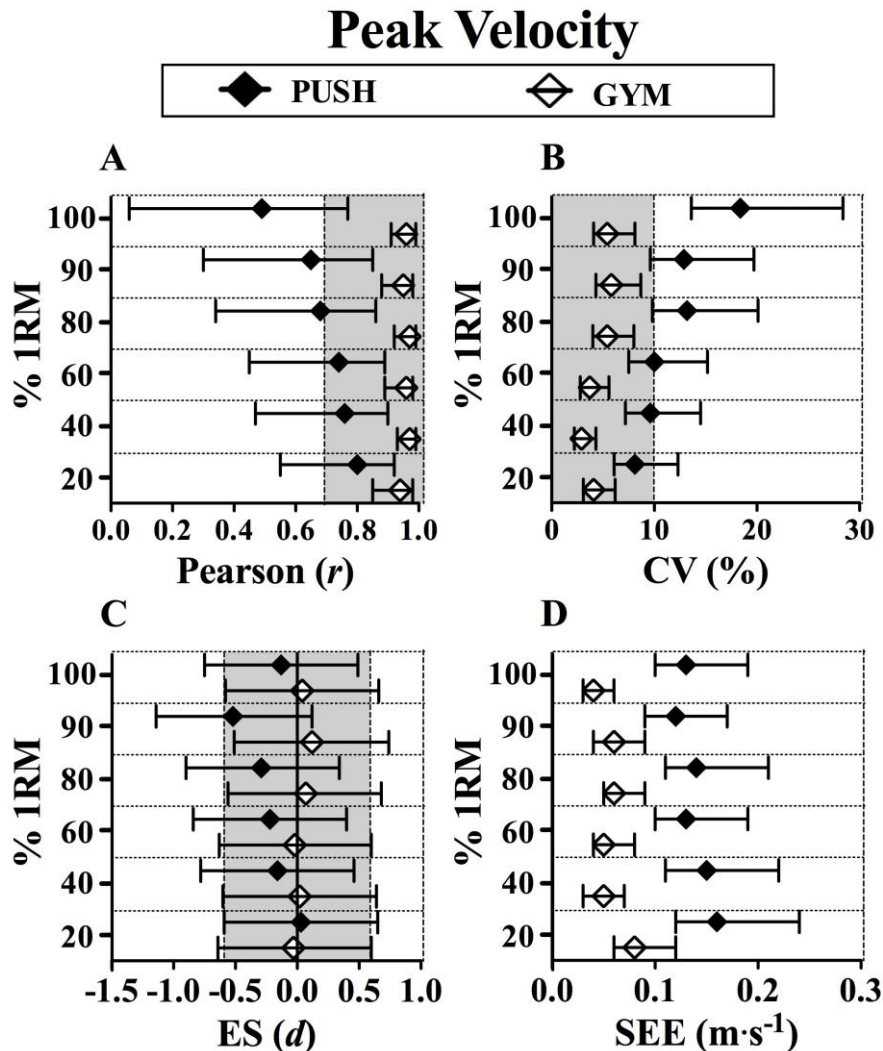


Figure 8. Validity of peak velocity in the back squat for the PUSH and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1-repetition maximum (1RM) compared with Laboratory methods. Forest plots displaying (A) Pearson correlation coefficient, (B) coefficient of variation, (C) effect-size estimates, and (D) standard error of the estimate. Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.

As previously mentioned, two studies have investigated the validity of the PUSH to measure MV and PV. Balsalobre-Fernández et al. [39] compared the measurements of the PUSH to a single LT (T-force) in the full depth Smith machine back squat. Ten physically active male participants performed five sets of three repetitions with the five incremental loads pertaining to 20 kg, 40 kg, 60 kg, and 70 kg (anecdotally suggested to represent 25 to 85% 1RM for each participant). When

all 150 repetitions (every repetition for each subject) were combined for their validity analyses the PUSH accurately measured MV ($r = 0.85$; $SEE = 0.08 \text{ m}\cdot\text{s}^{-1}$) and PV ($r = 0.91$; $SEE = 0.10 \text{ m}\cdot\text{s}^{-1}$). Interestingly, the correlation and measurement error results from Balsalobre-Fernández et al. [39] were comparatively similar to the PUSH measurements of MV ($r = 0.93$; $SEE = 0.10 \text{ m}\cdot\text{s}^{-1}$) and PV ($r = 0.91$; $SEE = 0.15 \text{ m}\cdot\text{s}^{-1}$) reported in the present study. However, the present study would suggest the PUSH was not accurate for measuring MV and PV due to the poor CV% and were not consistent with those reported by Balsalobre-Fernández et al. [39] for a similar action. This may be due to the difference in barbell paths between Smith machine (fixed linear action) and free-weight back squat.

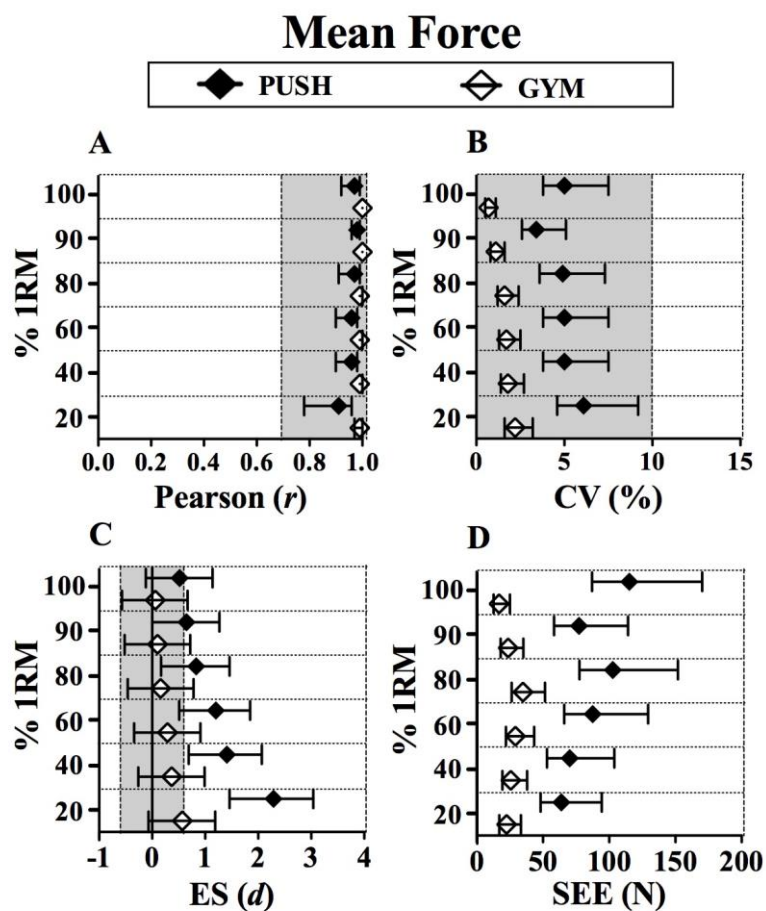


Figure 9. Validity of mean force in the back squat for the PUSH and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1-repetition maximum (1RM) compared with Laboratory methods. Forest plots displaying (A) Pearson correlation coefficient, (B) coefficient of variation, (C) effect-size estimates, and (D) standard error of the estimate. Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.

Similarly, Sato et al. [65] reported the validity of the PUSH for measurements of MV and PV compared to a 3D motion analysis capture system (VICON-Peak, Oxford Metrics, Oxford, UK) in the dumbbell bicep curl and dumbbell shoulder press exercises. Five recreationally trained participants performed both exercises with two sets of 10 repetitions at 4.54 kg, and two sets of 10 repetitions at 6.82 kg. Similar to Balsalobre-Fernández et al. [39], Sato et al. [65] combined all repetitions (200 repetitions) regardless of load for statistical analyses and concluded the PUSH was highly valid at measuring MV and PV for the bicep curl (MV: $r = 0.86$, $SEE = 0.09 \text{ m}\cdot\text{s}^{-1}$; PV: $r = 0.80$, $SEE = 0.16 \text{ m}\cdot\text{s}^{-1}$) and shoulder press exercises (MV: $r = 0.88$, $SEE = 0.06 \text{ m}\cdot\text{s}^{-1}$; PV: $r = 0.92$, $SEE = 0.11 \text{ m}\cdot\text{s}^{-1}$). These correlations and measurement error findings also compare well with the results from the present study (Figure 6) even though the modes of exercises investigated were different between studies but like the Balsalobre-Fernández et al., [39] study, Sato et al. [65] also did not report the CV. Although the findings of previous research validating the PUSH are helpful and accurately reflect how the data were analysed, they are somewhat limited since the validity of the PUSH was not reported at specific relative intensities. Importantly, the present study found the accuracy of the PUSH varies depending on the intensity lifted, which is important to discern as athletes often train at a variety of relative loads throughout the training year. Nevertheless, the aforementioned studies observed similar velocities to those determined in the present study when all repetitions were combined for analyses regardless of the load. Interestingly, Sato et al. [65] and Balsalobre-Fernández et al. [39] detected systematic bias for estimations of MV and PV by the PUSH which was not observed in the present study.

Unsurprisingly, the GYM accurately measured MV and PV across all relative loads. However, there were minor but non-significant differences observed between GYM (1 LT) and LAB (4 LTs) assessment of MV and PV. This was likely due to slight variations in horizontal and vertical displacement on either side of the barbell (bar path) that can occur when using a single LT [69]. This has been observed in previous research where Cormie et al. [70] assessed differences in the measurement of PV between 1 LT and 2 LTs for the jump squat exercise performed at 30 and 90% 1RM. They reported the 1 LT system significantly ($p < 0.05$) over predicted measurements of PV at 90% but not 30% 1RM compared to 2 LTs. However, contrary to the findings of Cormie et al. [70] we did not find any significant differences between the GYM and LAB for MV or PV at any relative intensity.

Peak Force

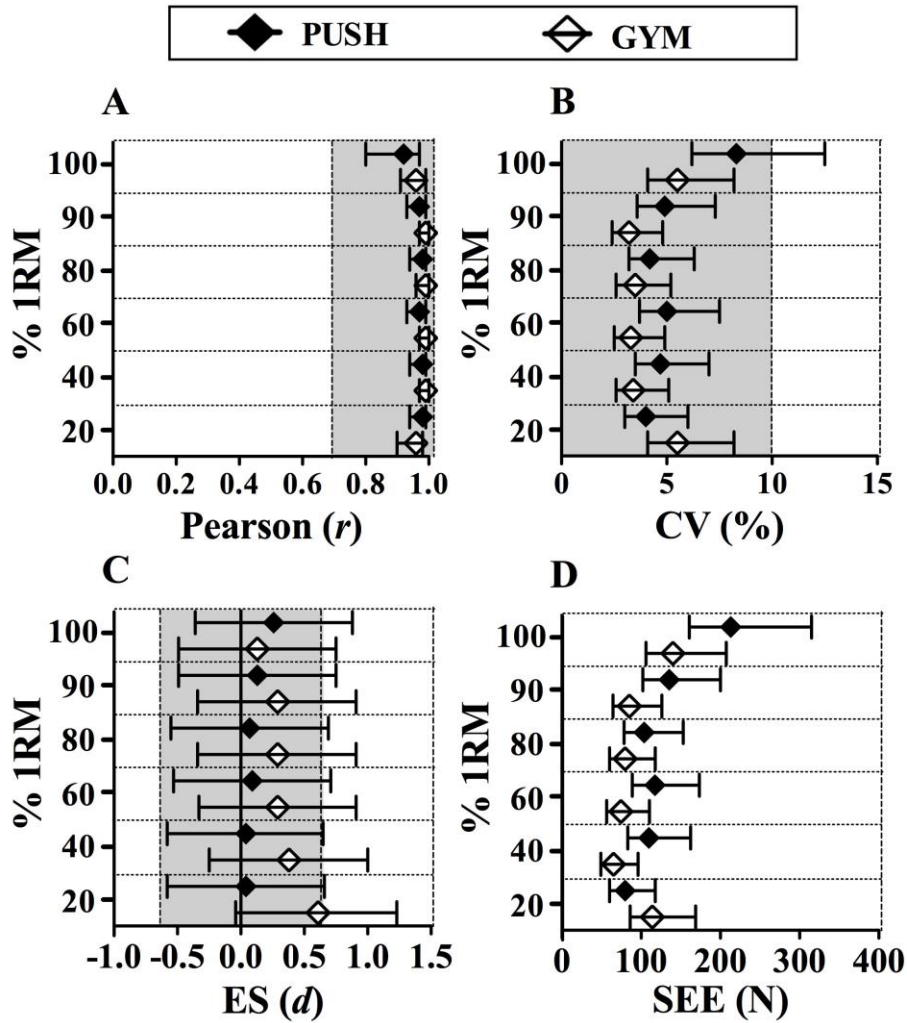


Figure 10. Validity of peak force in the back squat for the PUSH and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1-repetition maximum (1RM) compared with Laboratory methods. Forest plots displaying (A) Pearson correlation coefficient, (B) coefficient of variation, (C) effect-size estimates, and (D) standard error of the estimate. Area shed in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.

To our knowledge this is the first study to assess the accuracy of the PUSH to estimate force and power during the back squat. Uniquely, the PUSH accurately estimated PF across all relative intensities compared to LAB, yet was only highly valid for the estimation of MF at 1RM. In addition, the PUSH estimations of MP and PP were not highly valid at all relative intensities except for MP at 20% 1RM. Furthermore, the PUSH estimates of MP appeared to follow a linear trend across the six relative loads, which are not typically reported in the scientific literature [58].

The present study detected systematic bias in the PUSH estimations of PP and MF but not PF. Similarly, previous studies have identified the presence of systematic bias ($p < 0.05$) in accelerometers, most notably for estimations of PF and PP compared to direct assessments of ground reaction forces from a force plate (Force) and the combination of a force plate and LT (Power) methodologies [61, 64]. For example, Comstock et al. [61] observed systematic bias for an accelerometer (Myotest®, Myotest Inc, Sion, Switzerland) in the estimation of PF and PP compared to a force plate (Ballistic Measurement System Innervations Inc, Fitness Technology force plate, Skye, Australia) and LT (Celesco PT5A-250; Chatsworth, California, USA) method with the bench throw and jump squat exercises performed at 30% 1RM. Comparatively, the present study also observed systematic bias for estimations of PF and PP by the GYM, specifically for PP at 20% and 40% 1RM. Importantly, the systematic bias observed for estimations of PF and PP from a LT at light loads has previously been reported. Cormie et al. [70] also reported the presence of systematic bias for estimations of PF and PP derived with one LT compared to a force plate and LT method of force/power assessment at 30% 1RM for the jump squat exercise. Despite the presence of systematic bias in the present study for estimations of PF and PP by the GYM, the LT was still highly valid.

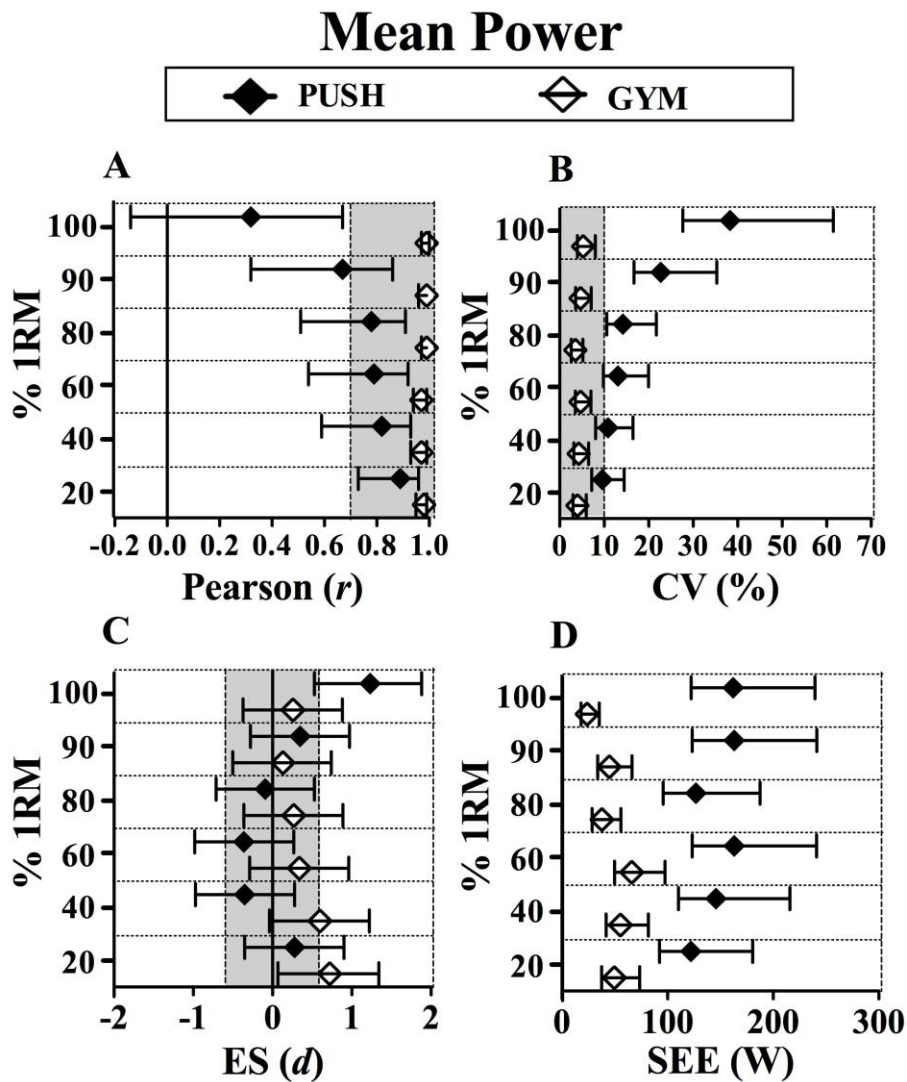


Figure 11. Validity of mean power in the back squat for the PUSH and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1-repetition maximum (1RM) compared with Laboratory methods. Forest plots displaying (A) Pearson correlation coefficient, (B) coefficient of variation (C) effect-size estimates, and (D) standard error of the estimate. Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.

The systematic bias observed for the GYM was also in accordance with Crewther et al. [64] who compared the accuracy of a LT (GymAware) and accelerometer (Myotest®, Myotest Inc. Switzerland) with a force plate (Kistler, Kistler Instruments Ltd, Farnborough, USA) to determine PF and PP with increasing loads (20 kg, 40 kg, 60 kg, and 80 kg) in the jump squat exercise. Systematic bias was detected at the lighter loads in the estimation of PF (20 and 40 kg) and PP (20 kg) for the GYM. Furthermore, moderate to high validity for PF and PP estimations in both the LT (PF: $r = 0.59$ to 0.87 , SEE = 39 to 202 N; PP: $r = 0.62$ to 0.82 , SEE = 45 to 401 W) and

accelerometer (PF: $r = 0.87$ to 0.97 , SEE = 7 to 171 N; PP: $r = 0.66$ to 0.90 , SEE = -180 to 141 W) were reported. If one compares the results of Crewther et al. [64] to the present study, the PUSH compares well with accelerometer devices for estimations of PF and PP. However, based on the correlation and SEE data, it appears the GYM is more accurate in the current study compared to previous research, possibly due to the less rapid speeds observed in the back squat exercise.

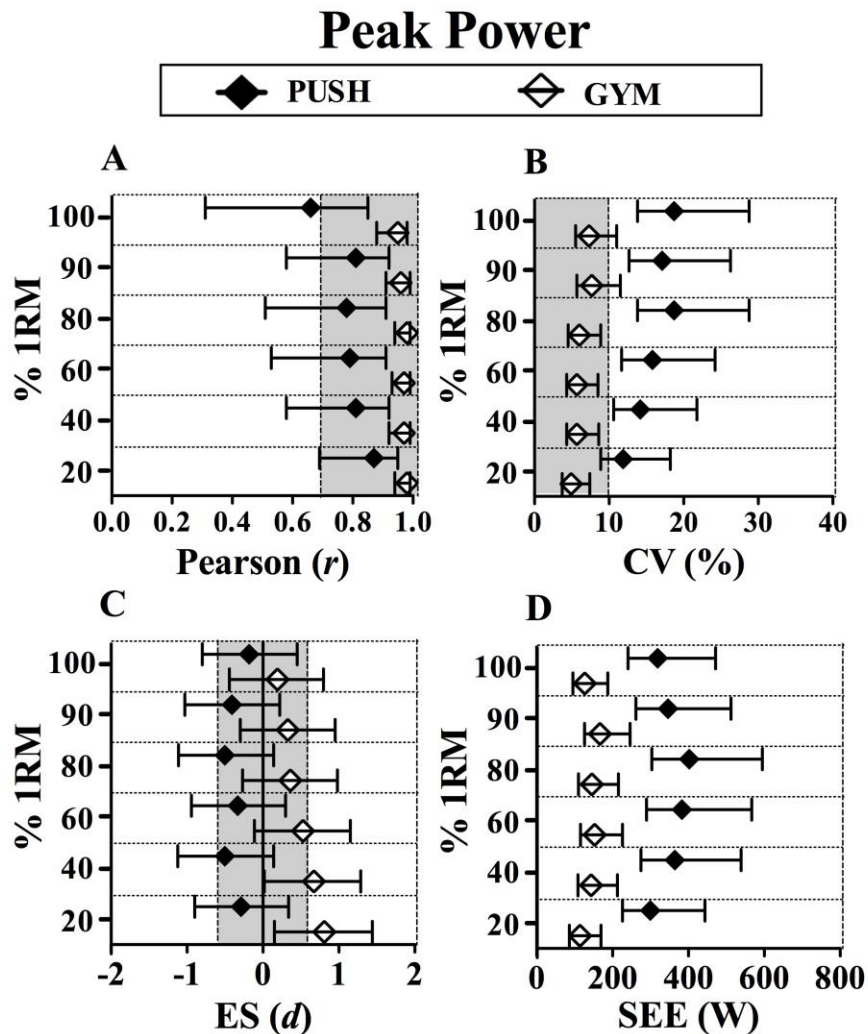


Figure 12. Validity of peak power in the back squat for the PUSH and GymAware devices at 20%, 40%, 60%, 80%, 90%, and 100% of 1-repetition maximum (1RM) compared with Laboratory methods. Forest plots displaying (A) Pearson correlation coefficient, (B) coefficient of variation, (C) effect-size estimates, and (D) standard error of the estimate. Area shaded in grey indicates the zone of acceptable validity. Error bars indicate 95% confidence limits.

Differences observed for the PUSH and GYM estimations of force and power compared to the LAB system were likely due to a multitude of factors. These include the different sampling

frequencies used with each device [76], disparities in the measurement of bar movements in the horizontal plane [69], and method of calculating force and power through the differentiation of accelerations and velocities which can magnify errors seen in data acquisition [64].

CONCLUSIONS

Our results suggest that even though systematic bias was present for the GYM assessment of PF and PP, the GYM is a valid field based device, which can accurately measure velocity, and is highly valid for the estimations of force. However, the GYM was problematic for the estimation of MP and PP at lighter loads in the back squat exercise. By comparison, the PUSH was able to accurately estimate PF at all relative intensities, and determine MV at light to moderate loads. However, the validity of the PUSH to measure anything other than PF in the back squat exercise performed across a spectrum of relative loads appears questionable.

PRACTICAL APPLICATIONS

The present study suggests practitioners should be cautious if prescribing/modifying sessional training loads or monitoring training adaptations for any variable other than PF using the PUSH, particularly at slower velocities. By comparison, the GYM, although not quite as sensitive as LAB testing methods, is highly valid and sensitive enough to be used as a tool to monitor training except for MP and PP at faster velocities.

CHAPTER 4: STUDY2

RELIABILITY AND VALIDITY OF THE LOAD-VELOCITY RELATIONSHIP TO PREDICT THE 1RM BACK SQUAT

Banyard HG, Nosaka K, & Haff GG.

The Journal of Strength and Conditioning Research

ABSTRACT

Purpose: This study investigated the reliability and validity of the load-velocity relationship to predict the free-weight back squat 1RM. Seventeen strength-trained men performed three 1RM assessments on three separate days, 48 hours apart. **Methods:** All repetitions were performed to full depth with maximal concentric effort. Predicted 1RMs were calculated by entering the MV of the 1RM (V_{1RM}) into an individualised linear regression equation, which was derived from the load-velocity relationship of 3 (20%, 40%, 60% 1RM), 4 (20%, 40%, 60%, 80% 1RM), or 5 (20%, 40%, 60%, 80%, 90% 1RM) incremental warm-up sets. **Results:** The actual 1RM (140.3 ± 27.2 kg) was very stable between 3 trials (ICC = 0.99; SEM = 2.9 kg; CV = 2.1%; ES = 0.11). Predicted 1RM from 5 warm-up sets up to and including 90% of 1RM was the most reliable (ICC = 0.92; SEM = 8.6 kg; CV = 5.7%; ES = -0.02) and valid ($r = 0.93$; SEE = 10.6 kg; CV = 7.4%; ES = 0.71) of the predicted 1RM methods. However, all predicted 1RMs were significantly different ($p \leq 0.05$; ES = 0.71 – 1.04) from the actual 1RM. Individual variation for the actual 1RM was small between trials ranging from -5.6 to 4.8% compared to the most accurate predictive method up to 90% 1RM, which was more variable (-5.5 to 27.8%). Importantly, the V_{1RM} (0.24 ± 0.06 m·s⁻¹) was unreliable between trials (ICC = 0.42; SEM = 0.05 m·s⁻¹; CV = 22.5%; ES = 0.14). **Conclusions:** The load-velocity relationship for the full depth free-weight back squat showed moderate reliability and validity but could not accurately predict 1RM, which was stable between trials. Thus, the load-velocity relationship 1RM prediction method used in this study cannot accurately modify sessional training loads due to large V_{1RM} variability.

INTRODUCTION

The 1RM assessment is a well-established, valid and reliable method of determining maximal strength [77, 78]. However, the overall time commitment associated with performing 1RM assessments for large squads of team sport athletes can be problematic. In addition, maximal strength has been reported to change rapidly [13], and frequent testing can take valuable time away from training. Consequently, regression equations to estimate 1RM, utilising the maximum number of repetitions performed to concentric muscular failure with a sub-maximal load, have been established [79-82]. However, the accuracy of these equations may vary according to the type of exercise, amount of repetitions completed, gender, and training status [77, 83, 84]. Furthermore, if a strength coach wanted to frequently monitor changes in maximal strength using 1RM prediction equations, the requisite sets performed to exhaustion may result in excessive fatigue, and diminish the force generating capacity in subsequent sets performed within the same training session leading to lower strength gains and power adaptations [9, 10, 32]. Therefore, an alternate less fatiguing method for determining an individual's maximal strength is required.

Due to the advancement in kinetic and kinematic transducer technologies it is now possible to accurately measure bar velocity [18, 31]. Specifically, three methods to quantify concentric movement velocity include PV, MPV, and MV [31, 32, 51, 85]. Importantly, even though peak concentric velocity is a pertinent measure for explosive type resistance training exercises such as bench throws and countermovement jumps, mean concentric velocity is believed to better represent the different velocities observed through the entire phase of non-aerial movements like the squat [10, 18, 23, 51, 86]. That being said, Sánchez-Medina, Pérez and González-Badillo [32] suggested that during non-aerial movements, mean concentric velocity underestimates the barbell movement velocity at lighter loads due to the need for an individual to decelerate the barbell velocity at the top of the lift in order to maintain balance. Instead, they suggest using mean propulsive velocity, which measures the average velocity during the concentric phase of a lift when acceleration of the barbell is greater than the acceleration due to gravity (propulsive phase) [32]. However, even though mean propulsive velocity has been shown to be a key variable in many studies [18, 31, 32, 51], it is also noted that it may add an unnecessary level of complexity to velocity measurements for strength and conditioning practitioners [18].

During resistance training exercises, if repetitions are performed with maximal concentric effort and consistent displacement, heavier loads will be lifted at slower velocities than lighter loads. Furthermore, research has shown an inverse linear relationship exists between load and mean concentric velocity [23, 87]. As a result, it has been suggested that individualised linear

regression equations (using the load-velocity relationship) can be used to accurately predict the 1RM [22]. Although helpful, the predicted 1RM findings from Jidovtseff et al. [23] were completed using a pause between the eccentric and the concentric portions of the bench press exercise performed on a Smith machine. Exercises utilizing the stretch shortening cycle (SSC) are known to produce greater amounts of concentric force, velocity, and power than exercises performed with a pause technique or concentric only exercises [88]. Therefore, the mean concentric velocity used in the load-velocity relationship to predict 1RM is likely to differ in free-weight exercises compared to the back squat performed with a pause technique on a Smith machine. Furthermore, a traditional free-weight back squat with a barbell incorporates vertical and some horizontal movement [89]. However, a Smith machine back squat is performed with a vertical movement only. Thus, the combination of the Smith machine and pause squat technique would likely provide different results in the measurement of mean concentric velocity compared to the free-weight back squat. As a consequence, the results of Jidovtseff et al. [23] may not be applicable to strength training exercises performed with free-weights or without a pause between the eccentric and concentric portions of the lift. Moreover, since exercises utilizing the SSC are more frequently performed and known to provide great transfer to performance tasks such as running and jumping [86, 88, 90], it is important to understand whether the load-velocity relationship can predict the 1RM in these types of exercises.

Recently, a theoretical paper has suggested that the load-velocity relationship may be a useful tool for predicting the 1RM for the back squat exercise [22]. If the prediction was found to be precise, the movement velocity measured in sets performed during the warm-up of a strength training session could then be used to monitor any potential day-to-day variation in maximal strength that may occur when athletes are fatigued. Importantly, if the load-velocity relationship is sensitive enough to predict subtle changes in fatigued athletes the stability of its predictions must first be established in non-fatigued conditions when maximal strength is theoretically stable. Thus, for accurate sessional predictions of 1RM to occur the day-to-day variability of the 1RM and the MV at 1RM (V_{1RM}) in a free-weight back squat must first be established. Such a finding could then help to determine whether V_{1RM} could be used to predict changes in maximal strength throughout a season resulting in more accurately modified training loads. Therefore, the purpose of this study was to determine the reliability and validity of the load-velocity relationship to predict 1RM. It is hypothesized that the load-velocity relationship will be valid and reliable for the prediction of 1RM, with the 90% prediction being the most valid and reliable of the prediction methods.

METHODS

Experimental Design

In this study, we investigated the reliability and validity of the load-velocity relationship to predict 1RM for the back squat. The load-velocity relationship was used to develop individualised linear regression equations utilising mean concentric velocity of three (20%, 40%, 60% 1RM), four (20%, 40%, 60%, and 80% 1RM), or five (20%, 40%, 60%, 80%, and 90% 1RM) incremental loads. As a consequence, the individualised 1RM prediction models based on three, four, or five sets were termed 60%, 80%, and 90%, respectively. Once the individualised regression equation was determined, the V_{1RM} for that session was used in the regression equation to predict the 1RM (Figure 13).

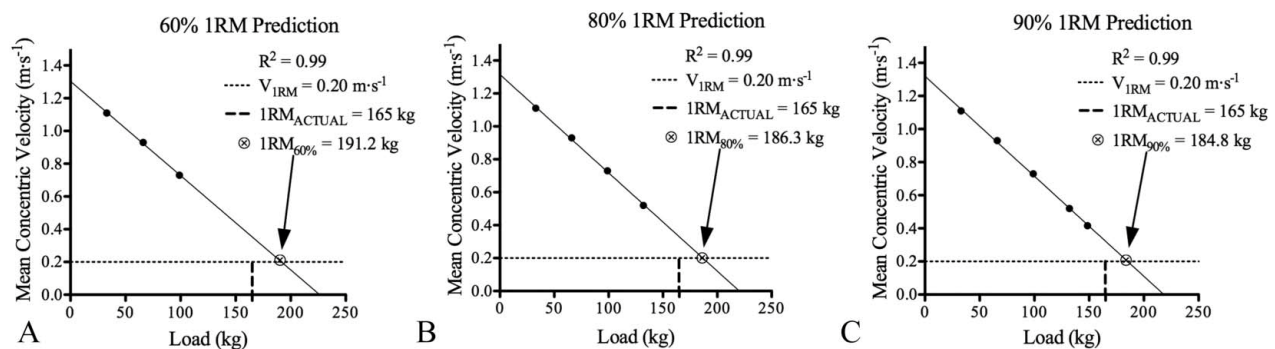


Figure 13. Predicted 1RM from the load–velocity relationship based on 20–60% of 1RM (A), 20–80% of 1RM (B), 20–90% of 1RM (C) of a typical sample. For this case, the predicted 1RM was 191.2 kg (A), 186.3 kg (B) and 184.8 kg (C), respectively.

Participants

Seventeen healthy male resistance-trained volunteers were recruited for this study (age: 25.4 ± 3.3 y, height: 181.6 ± 6.4 m, body mass: 81.8 ± 9.9 kg). All subjects were free from any musculoskeletal injuries, able to perform the full depth back squat with at least 1.5 times their body mass, and had 5.9 ± 2.9 years of resistance training experience, which ranged from 1 to 10 years. The subject's average 1RM back squat, 1RM to body mass ratio, and peak knee flexion angle at the bottom of the squat were: 140.3 ± 27.2 kg, 1.71 ± 0.16 kg·kg⁻¹, and $121.2 \pm 10.9^\circ$ respectively. All volunteers read and signed informed consent forms prior to participation in the present study in accordance with the ethical requirements of Edith Cowan University Human Research Ethics Committee.

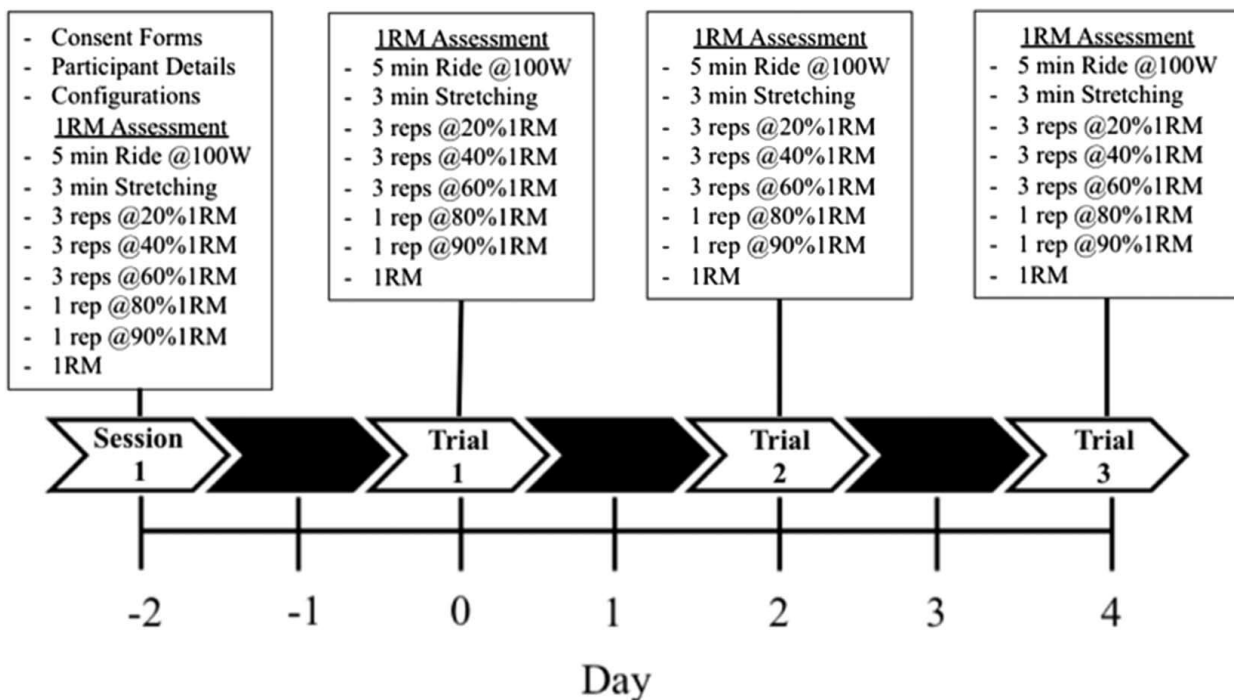


Figure 14. Experimental protocol. Session 1, Trial 1, 2, and 3 each comprised a 1RM assessment separated by 48 hours.

Experimental Procedure

All subjects performed four 1RM assessments with each trial separated by 48 hours (Figure 14). The initial 1RM assessment performed in the familiarization session was not included in the analyses of this study but was conducted so that accurate relative 1RM loads could be lifted for the remaining three 1RM sessions (trials 1, 2, and 3). In session 1, subjects were informed of the testing procedures and had their height, body mass, safety rack height and barbell rack height recorded. They then completed all required documentation, which was then followed by the initial 1RM assessment.

One-Repetition Maximum (1RM) Assessment

The 1RM assessments were performed in a custom-built power cage (Fitness Technology, Adelaide, Australia) using a 20-kg barbell (Eleiko®; Halmstad, Sweden). As shown in Figure 2, at the commencement of session 1 and each trial, the subjects performed a warm-up procedure consisting of five minutes pedalling on a cycle ergometer (Monark 828E cycle ergometer; Vansbro, Dalarna, Sweden) at 100 W at 60 revolutions per minute, three minutes of dynamic stretching, followed by a squat protocol comprising three repetitions at 20% 1RM, three repetitions at 40% 1RM, three repetitions at 60% 1RM, one repetition at 80% 1RM and one repetition at 90%

1RM (the load at each relative intensity was estimated for the initial 1RM assessment). The selection of multiple repetitions at 20%, 40%, and 60% 1RM was to establish a reliable MV without inducing fatigue as suggested by previous research [23]. For the repetitions performed at 20%, 40%, and 60% 1RM the highest mean concentric velocity was selected for analysis providing full depth was achieved, which is accordance with previous research [23]. For each 1RM assessment a maximum of five 1RM attempts were permitted which did not include the submaximal warm-up repetitions performed up to and including 90% 1RM. In consultation with each subject, following a successful 1RM attempt the barbell weight was increased between 0.5 and 2.5 kg until no further weight could be lifted. Rest periods comprised passive recovery of two minutes between warm-up sets and three minutes between 1RM attempts.

In the familiarization session a goniometer was used to measure knee angle at the bottom of the squat, which corresponded to a specific barbell depth that was recorded on a LabView analysis program. The barbell depth at full knee flexion was then monitored for each repetition by visual displacement curves on the LabView analysis program to ensure the same barbell depth was maintained throughout the assessments [19]. For each squat repetition, subjects were instructed to perform the eccentric phase in a controlled manner until full knee flexion was achieved. Once the eccentric phase was completed the subject was told to immediately perform the concentric phase as fast and explosively as possible (with the assistance of verbal encouragement) in order to utilize the SSC. Importantly, the barbell was placed in a high bar position on the superior aspect of the trapezius muscle and had to remain in constant contact with the shoulders while the feet were required to maintain contact with the floor. The heel and toe locations of each participant were recorded on the force plate using a one cm intersecting vertical-horizontal grid and the same position was maintained for every trial.

Data Acquisition

Barbell displacement and mean concentric velocity were monitored by four fixed position transducers (Celesco PT5A-250; Chatsworth, California, USA), which were mounted to the top of the power cage and attached to the side of the barbell [19]. The concentric phase of each repetition commenced at the point of maximal displacement (greatest descent) and terminated at zero displacement (standing). The position transducer data were collected via a BNC-2090 interface box with an analogue-to-digital card (NI-6014; National Instruments, Austin, Texas, USA) and sampled at 1000 Hz. In addition, the position transducer data were collected and analysed using a customised LabVIEW program (National Instruments, Version 14.0). All signals were filtered

with a 4th order-low pass Butterworth filter with a cut-off frequency of 50 Hz. The four transducers had a total retraction tension of 23.0 N, which was accounted for in all calculations.

Statistical Analyses

For trials 1, 2 and 3, individualised regression equations to predict 1RM were analysed using Excel Software (Microsoft; Redmond, Washington, USA). A Shapiro-Wilk test of normality was performed and indicated that all data were normally distributed ($p > 0.05$). Reliability of the 1RM, predicted 1RMs, and V_{1RM} was determined from the magnitude of the intraclass correlation coefficient (ICC), SEM, CV, and the ES [74]. Similarly, validity of the predicted 1RMs compared with the actual 1RM was assessed from the magnitudes of the Pearson product moment correlation (r), SEE, CV, and the ES [74]. The magnitude of the ES (Cohen's d) was considered trivial (<0.2), small ($0.2 - 0.59$), moderate ($0.60 - 1.19$), large ($1.2 - 1.99$) or very large (>2.0) [75]. In addition, the strength of the correlations was determined using the following criteria: trivial (< 0.1), small ($0.1 - 0.3$), moderate ($0.3 - 0.5$), high ($0.5 - 0.7$), very high ($0.7 - 0.9$), or practically perfect (>0.9) [71]. Fisher's r to z transformation analysis was used to ascertain significant differences between 1RM and predicted 1RM. Magnitude of CV was based on the following parameters: poor ($>10\%$), moderate ($5 - 10\%$), or good ($<5\%$) [73]. Confidence limits were set at 95% for all reliability and validity analyses. Finally, 1RM comparisons for reliability and validity were also assessed using repeated measures analysis of variance with a type-I error rate set at $\alpha < 0.05$, and Tukey post hoc comparisons utilized where appropriate (IBM SPSS version 22.0, Armonk, New York, USA).

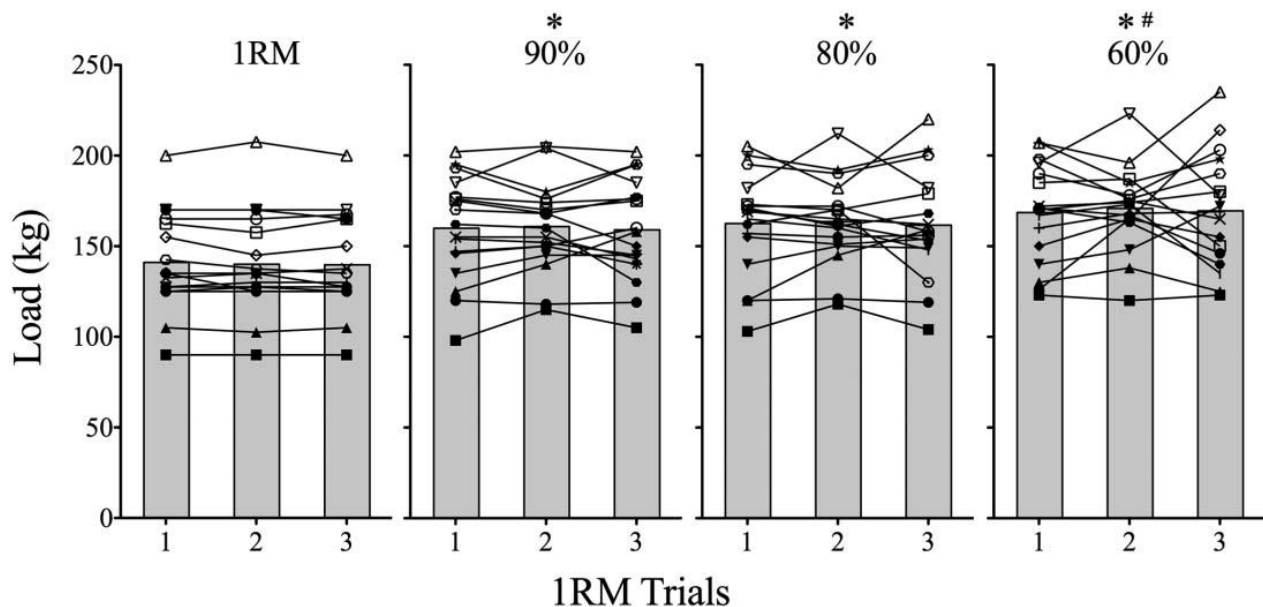


Figure 15. Individual variation of 1RM and predicted 1RMs between trials. The shaded bars indicate the group mean for that trial. *Significant difference between 1RM and predicted 1RM

up to 90%, 80%, and 60% 1RM; #Significant differences between the 90% and 60% 1RM predictions.

RESULTS

Reliability

No significant differences were seen between trials 1, 2, and 3 for the 1RM (140.7 ± 26.9 kg, 139.7 ± 27.8 kg, 140.4 ± 27.0 kg, $p > 0.05$), and 1RM predictions based on the submaximal measures up to 90% (159.7 ± 28.8 kg, 160.6 ± 24.7 kg, 158.8 ± 27.9 kg, $p > 0.05$), 80% (162.3 ± 28.3 kg, 163.3 ± 23.7 kg, 161.4 ± 29.6 kg, $p > 0.05$), and 60% (168.4 ± 27.3 kg, 170.6 ± 22.7 kg, 170.6 ± 34.5 kg, $p > 0.05$) (Figure 15). Individual variation ranges between trials for the 1RM (-5.6 to 4.8%) and 90% (-10.7 to 10.8%), 80% (-20.9 to 23.5%), and 60% (-22.0 to 35.8%) 1RM predictions are shown in Figure 15. ICC's for the 1RM (0.99), and 90% (0.92), 80% (0.87), and 60% (0.72) 1RM predictions were practically perfect, very high, and high, respectively (Figure 16C). Furthermore, a Fisher r to z transformation revealed no significant differences ($p > 0.05$) for the correlations between trials for the 1RM and predicted 1RMs. Interestingly, the 1RM was very stable between trials with a small SEM (2.9 kg) and good CV (2.1%), in addition to a trivial ES ($d = 0.03$), as seen in Figure 16. However, for the 90%, 80% and 60% 1RM predictions, there was a moderate to large SEM (8.6, 11.1, 16.8 kg), moderate to poor CVs (5.7, 7.2, 12.2%), but trivial ESs (-0.02, -0.05, -0.05), respectively. Lastly, the SEM ($0.05 \text{ m}\cdot\text{s}^{-1}$) and CV (22.5%) for the V_{1RM} ($0.24 \pm 0.06 \text{ m}\cdot\text{s}^{-1}$) were large and poor between trials although the ICC (0.42) was moderate, along with a trivial ES ($d = 0.143$).

Validity

All 1RM predictions were significantly different ($p < 0.001$) to the 1RM for all trials (Figure 15 & 18). Compared to the 1RM, there was considerable individual variation for the 90% (-5.5 to 27.8%), 80% (-12.3 to 29.4%), and 60% (-5.5 to 47.6%) 1RM predictions (Figure 15). Interestingly, the Pearson correlations for the predicted 1RMs up to 90% ($r = 0.93$), 80% ($r = 0.87$), and 60% ($r = 0.78$) were practically perfect or very high, as seen in Figure 17C. However, comparison of these correlations using Fisher's r -to- z transformation revealed that all three correlations were significantly different ($p < 0.001$) from the 1RM. In addition, the SEE revealed large absolute errors (10.6 kg, 12.9 kg, 17.2 kg), and moderate to poor CVs (7.4%, 9.1%, 12.8%) for the 90%, 80%, and 60% 1RM predictions, respectively (Figure 17A & 17B). The ES for the

magnitude of 1RM predictions ranged from 0.71 to 1.04, as seen in Figure 17D, indicating all 1RM predictions were moderately different to the 1RM.

DISCUSSION

The main finding of the present study was that in strength-trained subjects, the load-velocity relationship was not reliable and valid enough to accurately predict maximal strength for the free-weight back squat exercise over three trials, which did not support our hypothesis. Essentially, the V_{1RM} used in the load-velocity relationship to predict 1RM was too variable ($CV = 22.5\%$) between sessions. However, as expected, the load-velocity relationship was more accurate when lifts were performed at higher loads that more closely approached the actual 1RM, yet the predictions were still significantly different from the 1RM. The concept of greater accuracy at higher loads is well documented in the 1RM prediction literature [48]. For example, Mayhew et al. [91] reported the accuracy of repetition to failure methods of 1RM prediction were enhanced when higher loads were lifted. However, the need to obtain velocities at intensities that are close to 1RM for accurate sessional 1RM predictions defeats the rationale of employing the load-velocity relationship method, since its suggested purpose is to accurately predict 1RM and avoid frequent maximal testing [22]. As a result, this study suggests that if the V_{1RM} is applied in the linear regression equation to predict maximal 1RM, the load-velocity relationship cannot accurately predict daily or training session specific 1RM for the free-weight back squat exercise.

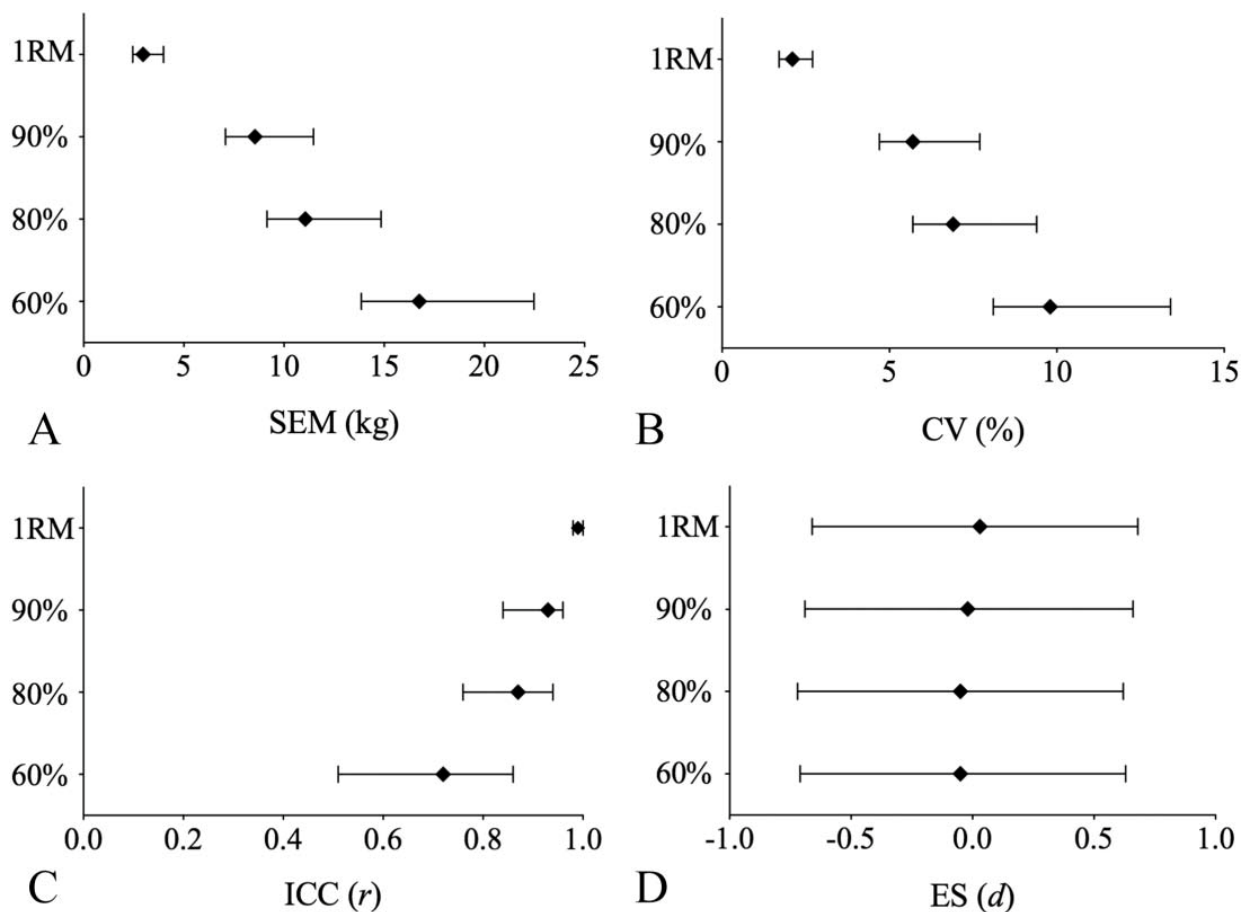


Figure 16. Reliability between trials of the 1RM and predicted 1RM up to 60%, 80%, and 90%1RM. Forest plots displaying: (A) SEM standard error of the measurement, (B) CV Coefficient of variation, (C) ICC intraclass correlation coefficient, and (D) the ES effect size estimates. Error bars indicate 95% confidence limits of the mean difference between trials.

The present study revealed that subjects who could lift at least 150% of their body mass were reliable at the back squat 1RM assessment as noted by the practically perfect correlation (ICC = 0.99), low measurement error (SEM = 2.9 kg; CV = 2.1%), and small individual variation (-5.6 to 4.8%) between trials. Interestingly, the 1RM reliability data in our study was similar to the correlation (ICC = 0.97), measurement error (SEM = 2.5 kg) and individual variation (-6.7 to 9.1%) between trials reported by Comfort and McMahon [24]. However, our investigation revealed that all predicted 1RMs were less reliable than the actual 1RM, evidenced by greater differences in the reliability analyses including the correlation (ICC), and measurement error (SEM and CV). If the load-velocity relationship were to be considered as a valid method to modify sessional training loads, the 1RM predictions would need to mimic the reliability statistics of the actual 1RM. Most notably, 1RM predictions would need to have practically perfect correlation,

trivial ES, small error of measurement and low CV, but these were not observed in the present study.

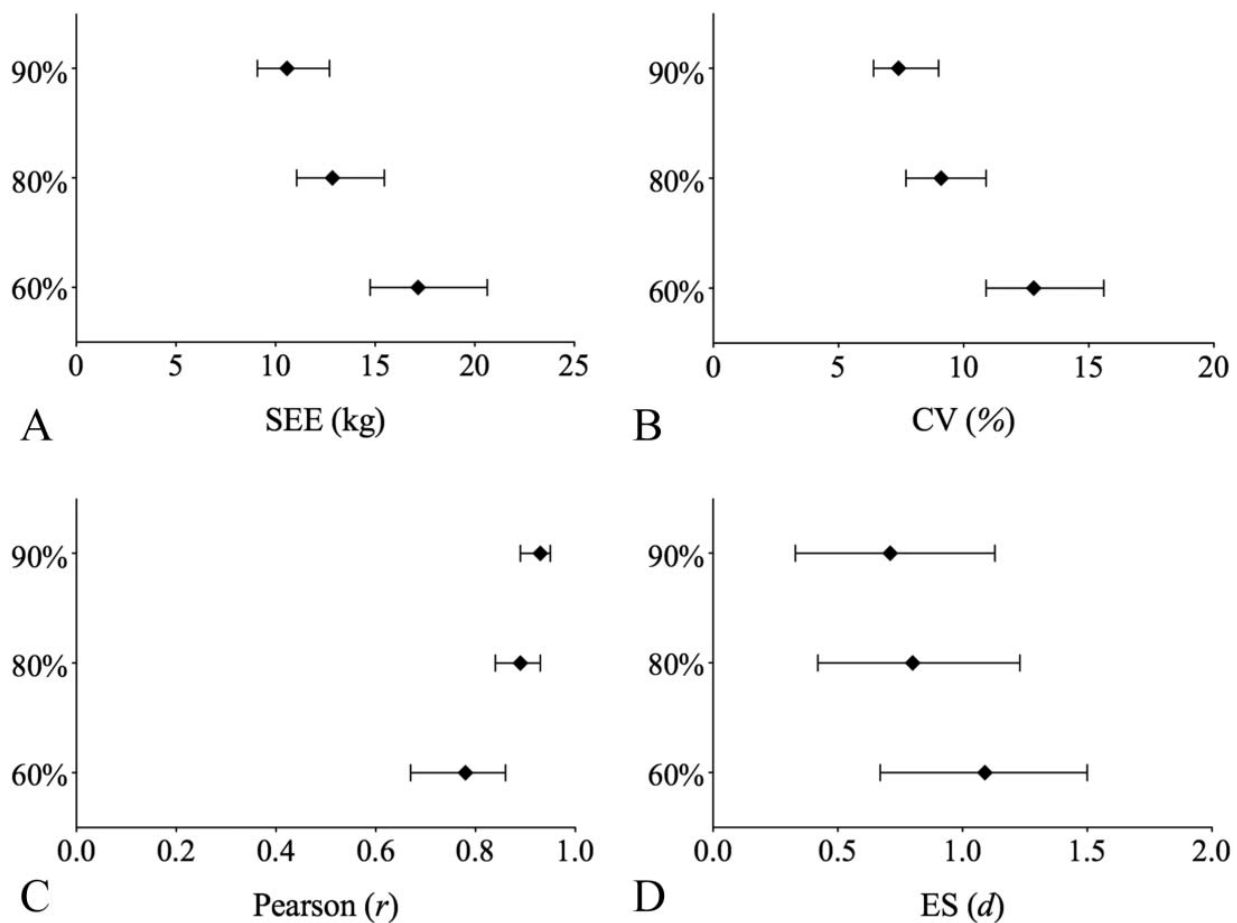


Figure 17. Validity of the predicted 1RM up to 60%, 80, and 90%1RM compared with 1RM. Forest plots displaying: (A) SEE standard error of the estimate, (B) CV Coefficient of variation, (C) Pearson correlation coefficient, and (D) the ES effect size estimates. Error bars indicate 95% confidence limits of the mean difference between 1RM and predicted 1RM.

Importantly, comparisons of the validity correlation data using Fisher's r-to-z transformation analysis revealed all predicted 1RMs significantly overestimated ($p < 0.05$) the actual 1RM. Therefore, the load-velocity relationship was unable to accurately predict maximal strength for the free-weight back squat exercise. This was further evidenced by large errors (SEE = 10.6 - 17.2 kg), moderate to poor CVs (7.4 - 12.8%), and moderate ESs (0.74 - 1.09). Consequently, if the load-velocity relationship cannot accurately predict a stable 1RM across three trials then it is unlikely to predict sessional training loads according to daily readiness. Interestingly, slightly lower correlations and higher measurement errors (SEE) were observed in the present investigation compared with the findings of two other 1RM prediction studies [23, 87].

Jidovtseff and colleagues [23] combined the data from three studies, culminating in 112 subjects (including 22 female) of recreational training status (1RM to body mass ratio = 0.85) performing concentric only bench press 1RM on a Smith machine. They then examined the linear regression equations, made from three or four sets performed up to 80%, 90%, or 95% 1RM, and analysed the relationship between bench press 1RM and the load at zero velocity (LD0). They found an almost perfect correlation ($r = 0.98$), yet noted a moderate measurement error (SEE = 7%). Similarly, Bosquet et al. [87] examined the validity of the force-velocity relationship (employing an undisclosed algorithm) to predict bench press 1RM. They had 27 participants (5 female) of recreational training status (1RM to body mass ratio = 0.87) perform the bench press 1RM on a Smith machine with a four second pause between eccentric and concentric phases. 1RM predictions were taken from an average of four trials that were performed until power decreased (approximately 48% of 1RM) during two consecutive loads. They reported a practically perfect correlation ($r = 0.93$), which aligned closely with the correlations found in the present study, and a measurement error of 9% (SEE). Although helpful, the practical usefulness of the findings from the two aforementioned studies is perhaps limited.

For example, the kinetic and kinematic data collected from exercises performed on a Smith machine are specific to that particular machine given the conceivable variation in barbell mass, angle of bar path and frictional forces between equipment. Moreover, even though pause and concentric only contractions minimise measurement error in concentric movement velocity [82], 1RM predictions using the pause or concentric only method provide limited ecological validity, as they do not reflect a true free-weight 1RM technique (no pause between eccentric and concentric phases), which utilises the SSC. Strength-training exercises incorporating the SSC are popular among athletes and are known to produce greater force than concentric only contractions [88]. Consequently, exercises incorporating the SSC can result in greater enhancement of performance tasks such as running and jumping. Therefore, to ensure ecological validity, if training with exercises utilising the SSC, the 1RM assessment (used to program relative intensities) must also incorporate the SSC. Furthermore, the pause or concentric only 1RM assessment would likely produce a lower 1RM load than a free-weight 1RM assessment. Consequently, it is likely the training adaptations would be compromised if one were to prescribe training intensity, for an exercise utilising the SSC, based off a pause or concentric only 1RM assessment.

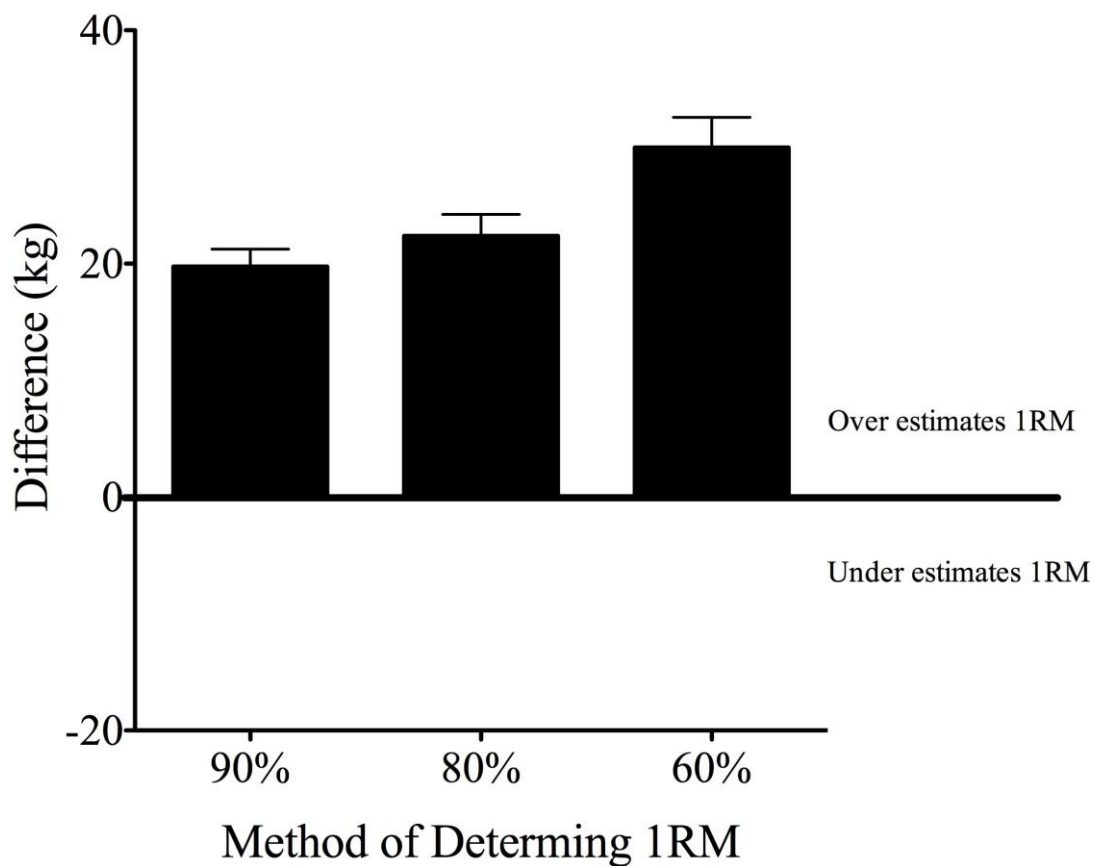


Figure 18. The average absolute difference between the 1RM and predicted 1RM up to 60%, 80%, and 90%1RM.

Another major finding in the present study was the greater individual variability of predicted 1RM when fewer sets were used for the estimation. This is in agreement with the findings of Jidovtseff et al. [23] who suggested that differences between the lightest and heaviest loads used for prediction should exceed $0.5 \text{ m}\cdot\text{s}^{-1}$. Moreover, the large variability between trials of the V_{1RM} also enhanced the measurement error in the predicted 1RMs for the free-weight back squat. In contrast, another study found the V_{1RM} was reliable for the 1RM back squat when a four second pause was incorporated between the eccentric and concentric phase [51]. Although rest/pause or concentric only assessments may not provide perfect ecological validity for exercises incorporating the SSC, they have been shown to provide reliable movement velocities at submaximal and maximal intensities [31, 51]. It is well established that if maximum effort is provided on the concentric phase of a lift, the associated movement velocity will decrease as fatigue ensues [18]. Therefore, isoinertial assessments using a pause or concentric only method

maybe beneficial as a fatigue monitoring tool by quantifying changes in MV for a given relative load.

When examining the findings of the present study the lack of ability to accurately and reliably predict 1RM on a daily basis with the use of velocity measures calls into question the theoretical model presented by Jovanovic and Flanagan [22]. Specifically, Jovanovic and Flanagan [22] suggested that the use of daily predictions of maximal strength could be made from the measurement of barbell velocity and training loads could then be adjusted based upon the predicted maximums in order to account for the athlete's current fatigue status. However, the present study clearly shows that in a recovered state the prediction of 1RM is highly variable when using velocity and results in a systematic over-estimation of the actual 1RM (Figure 18). As such, it is highly likely that when athletes are fatigued, further variability will be noted. Therefore, based upon the present study it is not recommended to use 1RM predictions as a tool for adjusting training loads to account for fatigue status. However, it is likely that sound periodization methods, such as incorporating heavy and light training days will appropriately account for the changing status of the athlete. For example, traditional periodization literature recommends adjusting training loads by 5 – 10% across the training week to account for accumulative fatigue [85]. Interestingly, this classic recommendation for modulating intensity between heavy and light resistance training days would account for the 2.1% CV noted in the present study and allow for adjustments in training load according to daily fatigue.

Crucially, the findings of the present study regarding the 1RM prediction method (calculated by entering the V_{1RM} into a linear regression equation) are limited to the free-weight back squat exercise performed to full depth with a relatively homogenous strength-trained population. Moreover, even though we acknowledge this method was not accurate enough to predict 1RM, it does not necessarily mean that all approaches using the load-velocity relationship would fail. Future studies may look to determine whether the accuracy of 1RM predictions in free-weight exercises can be improved by using alternative non-linear regression models or other variables such as PV or MPV. In addition, it is not well understood whether the accuracy of 1RM predictions is affected by exercise selection, age, gender, or training status.

CONCLUSIONS

Based on the results of the present study, it appears the load-velocity prediction of the free-weight back squat 1RM performed to full depth is moderately reliable and valid but not accurate enough to predict maximal strength on a daily basis. This was primarily due to the poor reliability

of the V_{1RM} . Consequently, performing sessional 1RM predictions to track changes in maximal strength and adjust sessional training loads according to daily readiness appears unlikely. However, if training for maximal strength gains, the variation in velocity may not matter providing maximal effort is given through the concentric phase of the lift. Furthermore, fluctuating the training intensity using sound periodisation could also account for daily readiness. Although, if an individual is performing power-based training where specific velocities are to be achieved then sessional adjustment of load by monitoring velocity maybe useful.

PRACTICAL APPLICATIONS

It is important to note the practical applications that stem from this work, most notably, even though the load-velocity relationship up to 90% of 1RM only provides a moderate estimation of 1RM, it holds similar validity to other predicted 1RM methods. However, for programming purposes, strength-trained individuals are recommended to periodise relative loads from a periodic 1RM assessment and account for daily readiness or envisaged fatigue by systematically modifying volume or intensity in accordance with periodization strategies and athlete monitoring programs. Future studies using free-weight exercises may monitor changes in movement velocity at relative submaximal loads to modify training sessions, but this has yet to be established as a reliable method of monitoring training loads in free-weight exercises.

CHAPTER 5: STUDY 3

THE RELIABILITY OF INDIVIDUALISED LOAD-VELOCITY PROFILES

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ABSTRACT

Purpose: This study examined the reliability of PV, MPV, and MV in the development of LVPs in the full depth free-weight back squat performed with maximal concentric effort. **Methods:** Eighteen resistance-trained men performed a baseline 1RM back squat trial and three subsequent 1RM trials used for reliability analyses, with 48-hours interval between trials. 1RM trials comprised lifts from six relative loads including 20%, 40%, 60%, 80%, 90%, and 100% 1RM. individualised LVPs for PV, MPV, or MV were derived from loads that were highly reliable based on the following criteria: ICC >0.70, CV ≤10%, and Cohen's *d* ES <0.60. **Results:** PV was highly reliable at all six loads. Importantly, MPV and MV were highly reliable at 20%, 40%, 60%, 80% and 90% but not 100% 1RM (MPV: ICC = 0.66, CV = 18.0%, ES = 0.10, SEM = 0.04 m·s⁻¹; MV: ICC = 0.55, CV = 19.4%, ES = 0.08, SEM = 0.04 m·s⁻¹). When considering the reliable ranges, almost perfect correlations were observed for LVPs derived from PV_{20-100%} ($r = 0.91-0.93$), MPV_{20-90%} ($r = 0.92-0.94$) and MV_{20-90%} ($r = 0.94 - 0.95$). Furthermore, the LVPs were not significantly different ($p > 0.05$) between trials, movement velocities, or between linear regression versus second order polynomial fits. **Conclusions:** PV_{20-100%}, MPV_{20-90%}, and MV_{20-90%} are reliable and can be utilized to develop LVPs using linear regression. Conceptually, LVPs can be used to monitor changes in movement velocity and employed as a method for adjusting sessional training loads according to daily readiness.

INTRODUCTION

Resistance training intensity is typically derived from a percentage of an actual or estimated 1RM assessment [8]. Once a 1RM load is determined, a strength coach can periodise the relative intensity of the training sessions to maximize adaptation and allow for recovery [85]. Although this method is relatively simple and requires no monitoring equipment, an athlete's maximal strength can increase rapidly [13], suggesting that continued prescription of relative loads from a baseline 1RM could compromise adaptation. Alternatively, an athlete who may be excessively fatigued for a prescribed training session is still required to lift a load, which may exacerbate fatigue and prolong recovery time. Therefore, it is necessary to establish a more precise and less-demanding method of monitoring athlete's training that can be used to modify exercise intensity when necessary.

Research has demonstrated an inverse linear relationship exists between load and velocity (load-velocity profile [LVP]), meaning that if maximal effort is given for the concentric phase of a lift, heavier loads cannot be lifted with the same velocity as lighter loads [23, 31, 53, 66, 87]. Furthermore, if maximal concentric effort is provided within a training set for a consistent range of motion, velocity will decline as concentric muscular fatigue ensues [18]. Currently, it is not known what occurs to movement velocity between training sessions when an athlete is fatigued in non-ballistic type exercises such as the barbell back squat. It is hypothesized that when an athlete is fatigued they may perform repetitions with reduced movement velocity compared to their non-fatigued velocity. However, in order to monitor training induced changes in movement velocity, the reliability of movement velocity used to develop LVPs needs to be established. This is critical for a coach who needs to differentiate between true changes in their athlete's movement velocity as a result of fatigue or training induced adaptation, and not just the typical error observed between training sessions.

Previous studies have established LVPs for the prone pull-up, bench press, leg press, half squat, and full squat exercises [31, 51, 54]. The LVP regression equations reported by Conceição et al. [51] and Gonzalez-Badillo et al. [31] were obtained from the group mean of 15 and 56 subjects, respectively. It is important to discern that different athletes can produce unique movement velocities based on individual characteristics such as their limb biomechanics and expression of fibre types [92, 93]. Therefore group mean LVP equations may not be appropriate for accurate monitoring of individual athletes who generate faster or slower movement velocities than the group mean. Notably, Conceição et al. [51] and Gonzalez-Badillo et al. [31] did not report the baseline test/re-test reliability of movement velocity used to develop the LVPs of the subjects.

Therefore, it is difficult to establish the exact significance of their findings since the typical variation in movement velocity between testing sessions was not reported for their subjects in a non-fatigued state. However, a key finding from these studies was that LVPs are exercise specific. With this in mind, it is important to note that Conceição et al. [51] and Gonzalez-Badillo et al. [31] had subjects perform repetitions on a weight machine or Smith machine with a 3-4 second pause between the eccentric and concentric phase of the maximal effort concentric contractions (pause method). Conceição et al. [51] suggest the pause between eccentric and concentric phases can minimize measurement error by removing the influence of the SSC from the concentric contraction. Although the findings of the two aforementioned studies are valuable, it is possible that their results are not ecologically valid with free-weight exercises utilizing the SSC that also involve vertical and some horizontal barbell movements [89]. This is important to discern since exercises performed in a free-weight manner utilizing the SSC are more popular among athletes and have been shown to have greater transfer of training effects to sports performance compared to concentric only contractions, particularly in more complex multi-joint exercises [88, 90]. While studies examining the LVP to monitor training appear promising, no previous study has assessed the reliability of movement velocity used in LVPs when individuals are in a non-fatigued state across multiple assessments for a free-weight squat exercise.

Three methods are often employed to quantify concentric movement velocity, which include PV, MPV, and MV [31, 51, 85]. MPV has recently been popularized and has been utilized in the aforementioned load-velocity profiling studies for the pull-up, bench press, leg press, half squat, and full squat exercises [31, 51, 54]. In addition to utilizing MPV, Gonzalez-Badillo et al. [31] employed second-order polynomial regression over linear regression to improve the strength of the correlations for the LVPs. Despite the continued use of MPV, many velocity measurement tools quantify PV and MV but do not report MPV. Thus, the use of MPV and polynomial regression equations may add an unnecessary level of complexity to data analysis for strength and conditioning practitioners. However, it is not known whether MPV or the use of polynomial regression is necessary to develop reliable LVPs in free-weight exercises. Therefore, the purpose of this study was to investigate the reliability of PV, MPV and MV to develop LVPs and determine whether more complex polynomial regression is necessary to improve the relationship between load and velocity in a free-weight exercise.

METHODS

Participants

Eighteen resistance-trained male volunteers participated in this study (age: 27.2 ± 4.1 y, height: 180.2 ± 6.1 cm, body mass: 80.5 ± 8.7 kg). Subjects were able to perform the full back squat with at least 1.5 times their body mass, had at least six months of resistance training experience, were familiarized with the 1RM assessment and were free from musculoskeletal injuries. Each subject was provided with information regarding the study, completed a medical questionnaire and gave written informed consent prior to volunteering for this study in accordance with the ethical requirements of Edith Cowan University Human Research Ethics Committee and the Code of Ethics of the World Medical Association (Declaration of Helsinki). Subjects height, body mass, squat depth (knee angle) and barbell rack height were recorded, which was followed by a baseline 1RM assessment. Peak knee flexion angle at the bottom of the squat, average 1RM back squat, and 1RM to body mass ratio were: $122.6 \pm 11.4^\circ$, 142.3 ± 28.3 kg, and 1.74 ± 0.21 , respectively.

Experimental Design

The present study incorporated three 1RM trials to investigate the reliability of PV, MPV, and MV at 20%, 40%, 60%, 80%, 90% and 100% 1RM in the full depth back squat exercise. Subjects were required to wear the same footwear to each session and had their own testing sessions conducted at the same time of day on every occasion. No lifting belts or straps were used for this study. They reported to the laboratory on four occasions, which included a familiarization session (baseline 1RM assessment) and three subsequent 1RM trials with 48 hours between sessions. Previous research has shown that 24 or 48 hours is sufficient time for individuals to recover from a 1RM back squat [66, 78]. The baseline 1RM assessment was performed so that accurate relative intensities from 1RM could be lifted in the remaining three 1RM trials. Values of PV, MPV and MV were collected from all repetitions in the three 1RM trials and used for the reliability analysis.

Experimental Procedure

Prior to each 1RM assessment the subjects performed a warm up protocol comprising of cycling on an ergometer for five minutes (Monark 828E cycle ergometer; Vansbro, Dalarna, Sweden) at 60 revolutions per minute and 60 W, dynamic stretching for three minutes, followed

by the 1RM assessment. 1RM assessments consisted of five sets pertaining to 20% (3-repetitions), 40% (3-repetitions), 60% (3-repetitions), 80% (1-repetition), and 90% 1RM (1-repetition), which was followed by the first 1RM attempt [66]. The highest MV value of the three repetitions performed at 20%, 40%, and 60% 1RM, for each set was chosen for reliability analysis. Five 1RM attempts were allowed with three minutes passive recovery permitted between sets. All repetitions were performed in a custom-built power cage (Fitness Technology, Adelaide, Australia) using a 20 kg barbell (Eleiko®; Halmstad, Sweden). Between 0.5 and 2.5 kg was added to the barbell weight after successful 1RM attempts until no further weight could be lifted with correct technique. For each repetition, subjects had to achieve a pre-determined squat depth established from their familiarization session. This was completed by measuring the knee angle at the bottom of the squat using a goniometer, which corresponded to a specific barbell displacement depth that was recorded on a LabVIEW analysis program (National Instruments, version 14.0) [19, 66, 67, 94]. Each repetition was monitored by visual displacement curves to ensure the equivalent barbell depth was maintained. Each repetition required subjects to descend (eccentric phase) in a self-selected controlled manner until full knee flexion was achieved then immediately perform the ascending phase (concentric phase) as rapidly as possible while the subjects feet remained in constant contact with the floor and the barbell in constant contact with the superior aspect of the trapezius muscle.

Data Acquisition

Four fixed position transducers (Celesco PT5A-250; Chatsworth, California, USA) monitored the barbell displacement and velocity data, which was then collected via a BNC-2090 interface box with an analogue-to-digital card (NI-6014; National Instruments, Austin, Texas, USA) and sampled at 1000 Hz [19, 67, 94]. Data were then collected and analysed using a customized LabVIEW program with signals filtered with a 4th order-low pass Butterworth filter and a cut-off frequency of 50 Hz. Total retraction tension of the position transducers equated to 23 N, which was factored into all calculations. Each transducer was mounted to the top of the power cage and attached to the side of the barbell. In accordance with previous research, 4 LTs were utilized to quantify both vertical and horizontal movements from both sides of the barbell and establish a more accurate central displacement position [19, 67, 70, 94]. The eccentric phase of each repetition commenced at zero displacement (standing) and was completed at maximal displacement (greatest descent) whereas the concentric phase began at maximal displacement and terminated at zero displacement. PV was the maximum value of the velocity data collected during

the concentric phase of the repetition. MPV was determined as the average velocity of the concentric phase when acceleration of the barbell was greater than acceleration due to gravity [32]. MV was calculated as the average of the velocity data during the concentric contraction.

Statistical Analyses

Reliability of PV, MPV and MV at each relative intensity (20%, 40%, 60%, 80%, 90%, and 100% 1RM) was determined from the magnitude of the ICC, CV, and the ES. This study considered the criterion variables highly reliable if they met the following three criteria: very high correlation (>0.70) [66, 71], moderate CV ($\geq 10\%$) [66, 72], and a small ES (<0.60) [66, 95]. The smallest detectable difference (SDD), interpreted as the smallest measurement change that corresponds to a real difference beyond zero for PV, MPV and MV, was calculated as:

$$\text{SDD} = 1.96 \times \sqrt{2} \times \text{SEM}$$

where SEM is the standard error of the measurement [96,97], which was also reported. Relationships between relative load and velocity (LVP) were studied by fitting linear regression, and second order polynomials to the data. The strength of the LVPs was assessed using Pearson product moment correlation (r) analysis. Fisher's r to z transformation analysis was used to ascertain significant correlation differences [98]: for PV, MPV and MV at each relative intensity between the three 1RM trials; between the LVPs developed from PV, MPV and MV; between the linear regression and second-order polynomial fitted LVPs. Confidence intervals were set at 95% for all reliability analyses. Data are reported as mean \pm SD unless stated otherwise.

RESULTS

Group mean values over three 1RM trials for PV, MPV and MV at 20%, 40%, 60%, 80%, 90%, and 100% 1RM are presented in Figure 19. Test-retest reliability was high for the group's 1RM assessments (ICC = 0.99; CV = 2.0%; SEM = 2.6 kg; ES = 0.05). An inverse linear relationship was observed with the movement velocities except for MPV and MV at 100% 1RM, which was substantially lower than the linear trend of the velocities between 20% and 90% 1RM.

PV was highly reliable at all relative intensities, but MPV and MV were highly reliable for all relative intensities except for 100% 1RM (Figure 20). The low reliability observed at 100% 1RM was due to low correlations (MPV: ICC = 0.66; MV: ICC = 0.55) and poor CVs (MPV: CV = 18.0%; MV: CV = 19.4%). As seen in Table 1, SDD values for PV were the highest of the three movement velocities. In addition, the SDD for MPV were slightly higher than MV.

The group means at 100% 1RM for PV, MPV and MV across the three trials were $0.84 \pm 0.13 \text{ m}\cdot\text{s}^{-1}$, $0.26 \pm 0.06 \text{ m}\cdot\text{s}^{-1}$ and $0.24 \pm 0.05 \text{ m}\cdot\text{s}^{-1}$, respectively (Figure 21). The group mean movement velocities in trials 1 (PV: $0.84 \pm 0.14 \text{ m}\cdot\text{s}^{-1}$; MPV: $0.26 \pm 0.07 \text{ m}\cdot\text{s}^{-1}$; MV: $0.24 \pm 0.07 \text{ m}\cdot\text{s}^{-1}$), 2 (PV: $0.82 \pm 0.14 \text{ m}\cdot\text{s}^{-1}$; MPV: $0.26 \pm 0.07 \text{ m}\cdot\text{s}^{-1}$; MV: $0.24 \pm 0.07 \text{ m}\cdot\text{s}^{-1}$), and 3 (PV: $0.83 \pm 0.13 \text{ m}\cdot\text{s}^{-1}$; MPV: $0.25 \pm 0.06 \text{ m}\cdot\text{s}^{-1}$; MV: $0.24 \pm 0.04 \text{ m}\cdot\text{s}^{-1}$) were almost identical at 100% 1RM (Figure 21), yet the individual subject variation ranges between the three trials was moderate for PV (-10.8 to 12.2%) and extremely large for MPV (-34.8 to 41.0%) and MV (-36.3 to 32.5%).

Based on the reliability results from Figure 20 we created LVPs from relative intensities that were highly reliable. The LVPs included PV from 20 – 100% 1RM, while MPV and MV were created utilizing 20 – 90% 1RM (Figure 22). Once the LVPs were created we then fitted the velocity data with linear and second-order polynomial fits to determine if the added complexity was necessary to improve the correlations (accuracy) of the LVPs (Figure 22). Correlation ranges for the individualised linear regression LVPs (PV: $r = 0.89 - 0.99$; MPV: $r = 0.90 - 0.99$; MV: $r = 0.90 - 0.99$) and individualised polynomial regression LVPs (PV: $r = 0.89 - 0.99$; MPV: $r = 0.90 - 0.99$; MV: $r = 0.91 - 0.99$) were almost perfect. The Fisher r to z transformation revealed no significant differences for the correlations between the individualised linear and polynomial regression fits in trials 1, 2, or 3 for PV, MPV and MV. Furthermore, there were no significant differences between the correlations for the LVPs derived from the three different movement velocities.

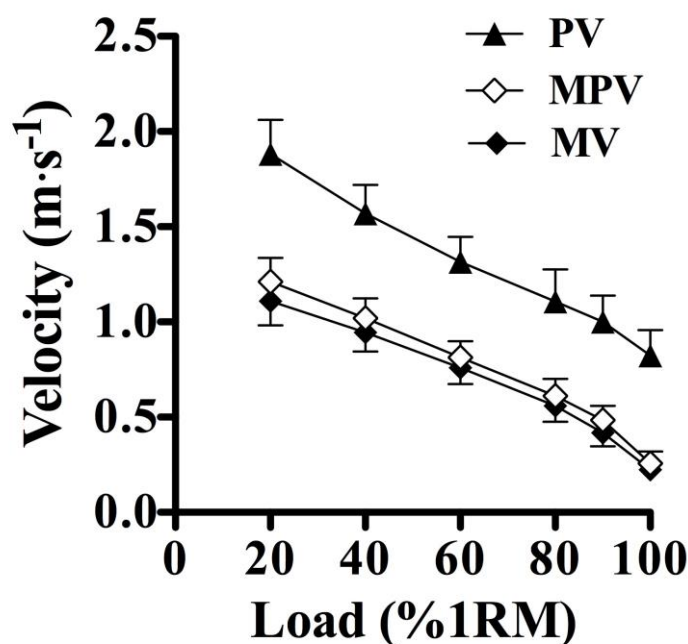


Figure 19. Group mean (SD) values from three 1RM trials for PV, MPV, and MV at 20%, 40%, 60%, 80%, 90%, and 100%1RM load. Abbreviations: 1RM, 1-repetition maximum; PV, peak velocity; MPV, mean propulsive velocity; MV, mean velocity.

DISCUSSION

The results of the present study advocate that PV was highly reliable at all six relative intensities tested including 100% 1RM. Similarly, MPV and MV were highly reliable at 20%, 40%, 60%, 80%, and 90% but not 100% 1RM. This suggests that all three-movement velocity types are acceptable to monitor changes in movement velocity (fatigue monitoring) for the free-weight squat exercise; however, a coach should not incorporate the movement velocity at 100% 1RM if the LVPs are created from MPV or MV. Moreover, there was no difference between the correlations of LVPs using linear regression or second-order polynomial fits.

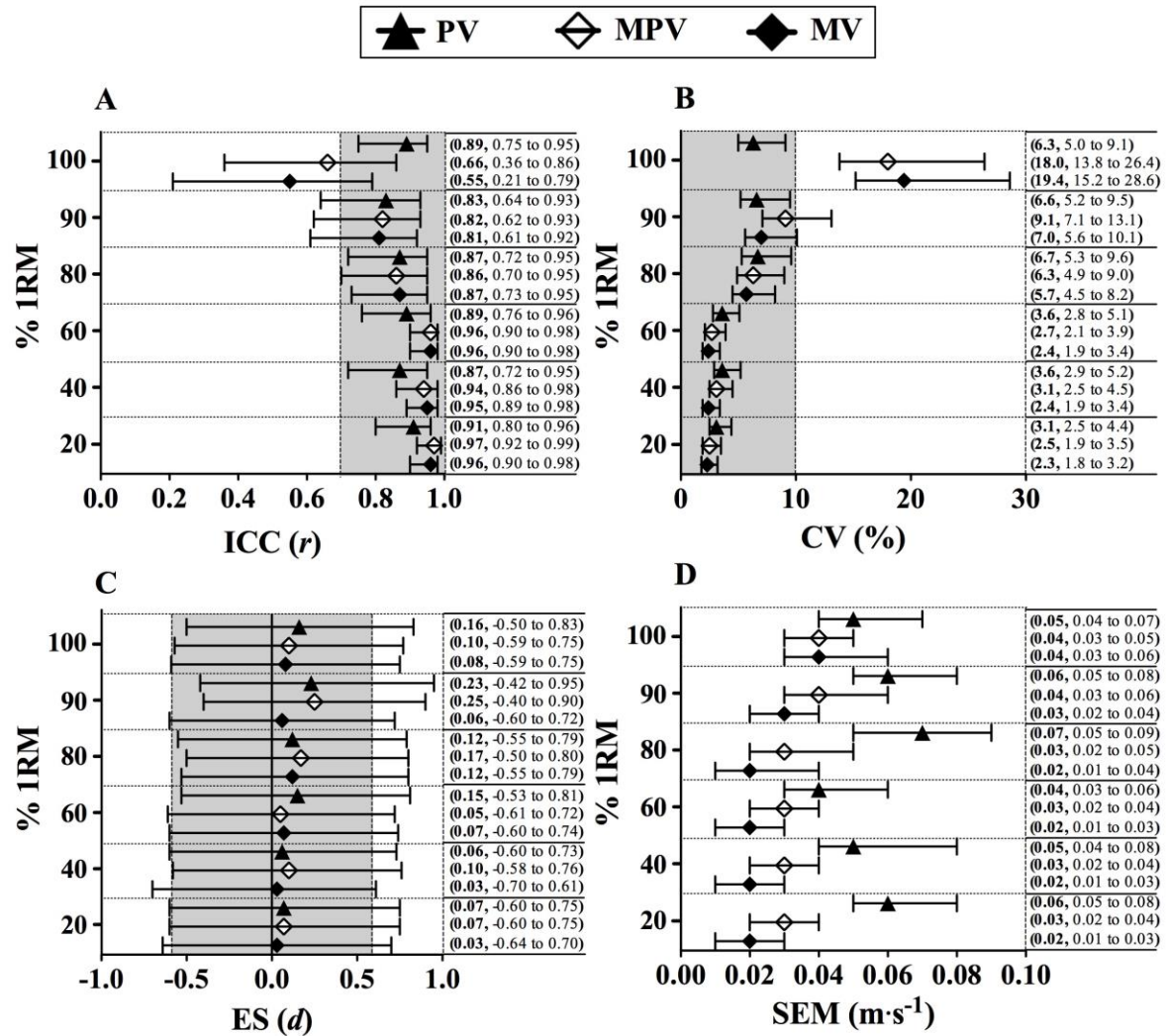


Figure 20. Reliability of PV, MPV, and MV in the back squat at 20%, 40%, 60%, 80%, 90%, and 100% 1RM. Forest plots displaying ICC (A), CV (B), ES estimates (C), and SEM (D). Gary-shaded area indicates the zone of acceptable reliability. Error bars indicate 95% confidence limits. Right y-axes contain the mean and 95% confidence limits. Abbreviations: PV, peak velocity; MPV, mean propulsive velocity; MV, mean velocity; 1RM, 1-repetition maximum; ICC, intraclass correlation coefficient; CV, coefficient of variation; ES, effect size.

Interestingly, the 100% 1RM values of MV ($0.24 \pm 0.05 \text{ m}\cdot\text{s}^{-1}$) reported in the present study are in line with the findings of Zourdos et al [99] ($0.24 \pm 0.04 \text{ m}\cdot\text{s}^{-1}$) who also assessed the full depth back squat. In addition, the poor reliability of MV at 100% 1RM observed in the present study (ICC = 0.55; CV = 19.4%; SEM = $0.04 \text{ m}\cdot\text{s}^{-1}$) is also in accordance with recent research (ICC = 0.42; CV = 22.5%; SEM = $0.05 \text{ m}\cdot\text{s}^{-1}$) for the free-weight back squat exercise reported elsewhere [66]. Research by Gonzalez-Badillo et al. [31] exploring the use of LVPs did not report the reliability of MPV at baseline, yet they found no statistically significant change in MPV (ICC

= 0.81 – 0.91; CV = 0.0 – 3.6%) at 5% incremental loads between 30% and 100% 1RM when 56 participants performed a bench press LVP before (trial 1) and after (trial 2) six weeks of upper body resistance training. They concluded that despite an average increase of 9.3% in maximal strength for their participant's over six weeks of training from trial 1 to trial 2, MPV was stable at each relative intensity [31]. To our knowledge, no studies have verified if this phenomenon is true for PV or MV. Therefore, even though PV and MV are reliable in the present study, future studies should establish whether PV and MV remain stable through the relative intensity spectrum if maximal strength changes.

The poor reliability observed in the current study for MPV and MV at 100% 1RM is likely due to small horizontal movements that can accompany the predominant vertical bar path in the free-weight back squat [89], as well as the inclusion of the SSC for the concentric contraction [82]. As a consequence, previous studies assessing LVPs to monitor fatigue have implemented the Smith machine and a pause or concentric only contraction to minimize the measurement error of concentric movement velocity in their LVPs and 1RM assessments [31, 51]. Despite this, the present study utilized the free-weight back squat and demonstrated that MPV and MV were reliable at all relative intensities except at 100% 1RM. Therefore movement velocity at 1RM should not be included with these movement velocities that make up the LVP. Importantly, exercises incorporating the SSC are known to result in greater force production than concentric only contractions [88]. Therefore, the methodology used by previous research may provide limited ecological validity for a back squat exercise, which athletes typically utilize in a free-weight manner with the SSC in order to maximize force production and enhance performance tasks like jumping. Furthermore, free-weight 1RM assessments are likely to produce higher 1RM loads than pause or concentric only 1RM assessments since greater force is produced in exercises utilizing the SSC compared with only concentric contractions [88]. As a consequence, training adaptation could be compromised if free-weight exercises are prescribed from pause or concentric only 1RM assessments.

Table 2. Recommendations for the smallest detectable difference of peak velocity (PV), mean propulsive velocity (MPV), and mean velocity (MV) at 20%, 40%, 60%, 80%, 90%, and 100% 1RM.

%1RM	PV (m·s ⁻¹)	MPV (m·s ⁻¹)	MV (m·s ⁻¹)
20	0.17	0.08	0.06
40	0.14	0.08	0.06
60	0.11	0.08	0.06
80	0.19	0.08	0.06
90	0.17	0.11	0.08
100	0.14	*0.11	*0.11

Note: * did not meet reliability criteria (ICC > 0.70, CV <10%, ES < 0.59).

To our knowledge, the present study is the first to report the reliability of PV, MPV and MV through the relative intensity spectrum, and subsequently utilize the reliable relative loads to develop LVPs in a free-weight exercise for strength-trained individuals in a non-fatigued state. Typically, PV is utilized to monitor impulsive type resistance training exercises such as the countermovement jump or bench throw, whereas MV is thought to better represent non-aerial movements like the squat or bench press through the entire concentric phase. Sanchez-Medina et al. [32] have suggested that MPV is more appropriate than MV at light and medium loads during non-aerial movements such as the squat because MV underestimates movement velocity when individuals decelerate the barbell at the top of the lift to maintain balance. Our results showed there were no significant differences between the correlations of the LVPs derived from PV, MPV, or MV. Furthermore, there were no significant differences between the correlations of the LVPs fitted with linear regression or second order polynomials for all three-movement velocities (Figure 22). This suggests that PV, MPV and MV are all suitable to develop LVPs if movement velocities at reliable relative loads are chosen for the profiles. Furthermore, the added complexity of fitting a second order polynomial to the LVP is unnecessary for the free-weight back squat. However, when a coach is selecting which movement velocity to employ to develop a LVP, they should be cognizant of the SDD (Table 2) associated with the different movement velocities when adjusting sessional training loads.

A recent study by Conceição et al. [51] tested 15 male track and field athletes and developed LVPs which were derived from PV and MPV at 5% incremental loads from 15% to 100% 1RM, for the incline machine leg press, full squat and half squat exercises performed on a Smith machine. They anecdotally suggested PV and MPV were stable for all exercises but did not report any reliability findings as the subjects were only tested once for each exercise. Therefore it is difficult

to ascertain if the LVPs derived from the study of Conceição et al. [51] were stable and could be used to monitor fatigue (declines in movement velocity). In addition, Conceição et al. [51] provided a group mean equation for each exercise which individuals can use to determine their relative intensity for a given movement velocity. Although a generalized LVP equation is helpful and has some validity, the present study suggests that LVPs are highly individualised. For example, although movement velocity is highly reliable, the ranges of measurements for PV at 20% ($1.62 - 2.30 \text{ m}\cdot\text{s}^{-1}$), 40% ($1.36 - 1.96 \text{ m}\cdot\text{s}^{-1}$), 60% ($1.09 - 1.60 \text{ m}\cdot\text{s}^{-1}$), 80% ($0.84 - 1.29 \text{ m}\cdot\text{s}^{-1}$), 90% ($0.70 - 1.12 \text{ m}\cdot\text{s}^{-1}$), and 100% 1RM ($0.58 - 0.91 \text{ m}\cdot\text{s}^{-1}$) were vastly different between individuals. As a consequence, coaches should create individualised LVPs for each athlete to improve the accuracy of monitoring changes in movement velocity and modifying training loads. The concept of individualizing training to enhance performance is in accordance with Jiménez-Reyes et al. [100] who individualised force-velocity profiles to maximize adaptations in jump performance.

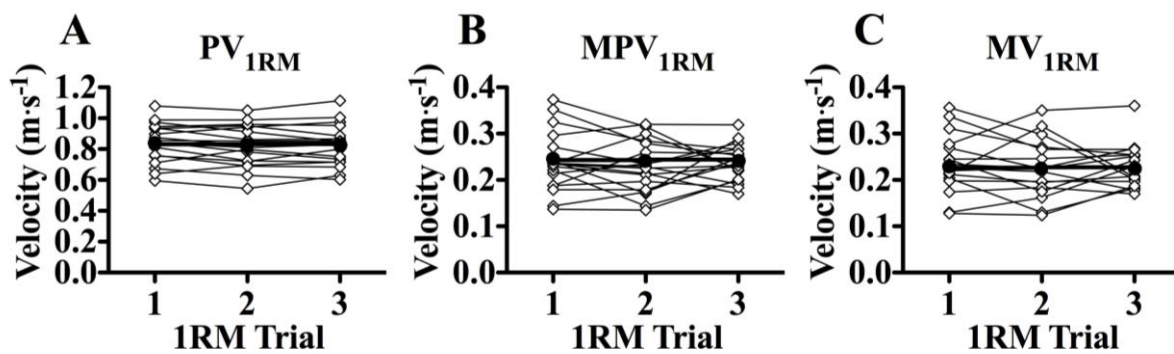


Figure 21. Individual variation and the group mean of PV (A), MPV (B), and MV (C) at 100% 1RM for trials 1–3. The black circles indicate the group mean for the relevant 1RM trial. PV indicates peak velocity; MPV, mean propulsive velocity; MV, mean velocity; 1RM, 1-repetition maximum.

Commonly, coaches monitor fatigue by tracking reductions in peak force using maximal isometric force assessments (isometric mid-thigh pull) or PV with ballistic power tests (CMJ) [56, 101]. These tests are proven to be valid and reliable but these assessments do not precisely identify how training loads can be modified for a specific exercise such as the squat. The present study has demonstrated that PV, MPV or MV can all be used to modify training load in the free-weight back squat if consistent barbell displacement and maximal concentric effort are provided. Therefore, coaches can use movement velocity as an accurate monitoring tool to determine an athlete's level of effort and adjust training load in a specific exercise if movement velocity targets are not met.

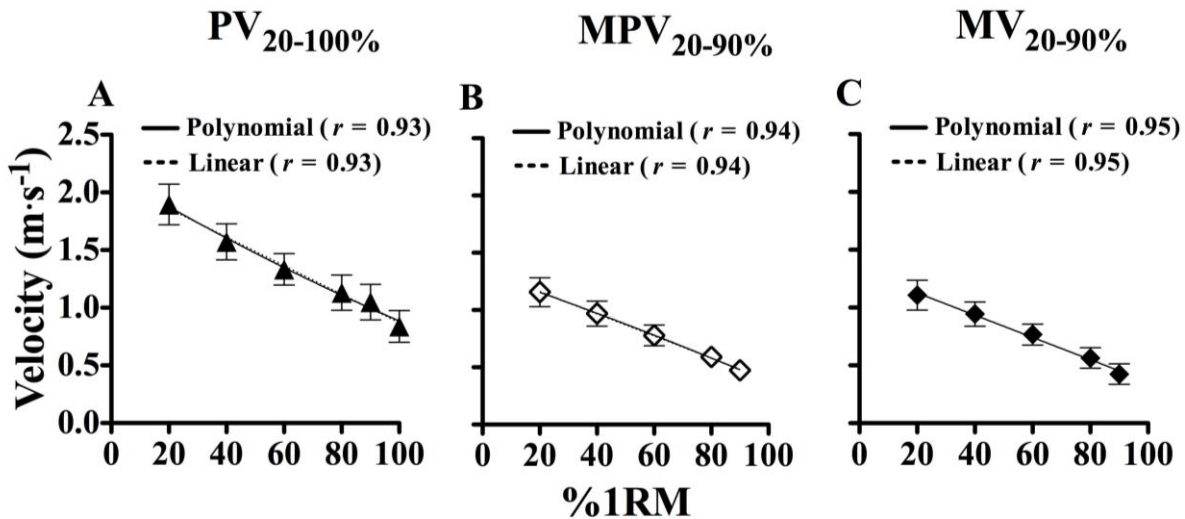


Figure 22. Load–velocity profiles obtained from group mean data (SD) using a second-order polynomial fit and a linear regression fit between relative load and (A) PV from 20% to 100% 1-RM (PV_{20-100%}), (B) MPV from 20% to 90% 1-RM (MPV_{20-90%}), and (C) MV from 20% to 90% 1-RM (MV_{20-90%}). PV indicates peak velocity; 1-RM, 1-repetition maximum; MPV, mean propulsive velocity; MV, mean velocity.

The results from the present study and previous research investigating LVPs for modifying the load in training sessions are encouraging. However, some caution should be taken from the results particularly in the practical setting due to the specificity of the associated methodology of the testing assessments. For example, the findings from the present study do not necessarily transfer to other exercises commonly utilized by athletes. Future studies should seek to investigate load-velocity profiling for each exercise performed by the athlete in order to modify lifting loads during training. In addition, if an individual intends to develop a LVP for the back squat exercise using MPV or MV, training velocities derived from the load-velocity relationship at relative loads greater than 90% 1RM may not be reliable. Therefore, LVPs utilizing MPV and MV could be problematic when training at near maximal relative intensities in the free-weight back squat. Crucially, the results obtained from this study are representative of a population who could lift between 150 to 240% of their body mass for at least one repetition. If someone were to employ load-velocity profiling as part of their training paradigm they would need to collect this data on their athlete population as part of their athlete testing/monitoring program. As discussed previously, if an athlete was to employ VBT methods, their own individualised LVP should be obtained. In addition, if the movement velocity is outside the range of the SDD (Table 2), a coach could modify the training load to achieve the requisite velocity from the LVP. However, further research is needed to further verify if this is an effective method of training.

CONCLUSIONS

In summary, PV, MPV and MV are reliable and can be used to develop LVPs in the full depth free-weight back squat. This suggests that movement velocity could be monitored in training and the sessional training loads may be adjusted according to daily readiness. Interestingly, it appears unnecessary to employ the added complexity of fitting second-order polynomials, compared to linear regression, to improve the accuracy of the LVPs. Furthermore, since there were no significant differences between the LVPs developed from the three movement velocities, we would suggest the utilization of PV, MPV or MV would be appropriate to develop LVPs with linear regression fits.

PRACTICAL APPLICATIONS

The present study suggests that if practitioners are to utilize LVPs to train competent athletes in a free-weight back squat, their athlete should: (1) perform a 1RM assessment; (2) conduct an individualised LVP using $PV_{20-100\%}$, $MPV_{20-90\%}$, or $MV_{20-90\%}$; (3) employ a linear regression equation and convert a relative intensity table (convert the % 1RM to velocity) into a movement velocity (PV, MPV, or MV) table; (4) modify training loads based on the SDD of their athlete at the required training load.

CHAPTER 6: STUDY 4

COMPARISON OF VELOCITY-BASED AND TRADITIONAL 1RM-PERCENT-BASED PRESCRIPTION ON ACUTE KINETIC AND KINEMATIC VARIABLES

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ABSTRACT

Purpose: This study compared kinetic and kinematic data from three different VBT sessions and a PBT session using full-depth, free-weight back squats with maximal concentric effort. **Methods:** Fifteen strength-trained men performed four randomized resistance-training sessions 96-hours apart: PBT session involved five sets of five repetitions using 80% 1RM; LVP session contained five sets of five repetitions with a load that could be adjusted to achieve a target velocity established from an individualised LVP equation at 80% 1RM; fixed sets 20% velocity loss threshold (FS_{VL20}) session that consisted of five sets at 80% 1RM but sets were terminated once the MV dropped below 20% of the threshold velocity or when five repetitions were completed per set; variable sets 20% velocity loss threshold (VS_{VL20}) session comprised 25-repetitions in total, but participants performed as many repetitions in a set as possible until the 20% velocity loss threshold was exceeded. **Results:** When averaged across all repetitions, MV and PV were significantly ($p < 0.05$) faster during the LVP (MV: ES = 1.05; PV: ES = 1.12) and FS_{VL20} (MV: ES = 0.81; PV: ES = 0.98) sessions compared to PBT. Mean time under tension (TUT) and concentric TUT were significantly less during the LVP session compared to PBT. FS_{VL20} session had significantly less repetitions, total TUT and concentric TUT than PBT. No significant differences were found for all other measurements between any of the sessions. **Conclusions:** VBT permits higher velocity maintenance, avoids additional mechanical stress but maintains similar measures of force and power output compared to strength-oriented PBT within a single session.

INTRODUCTION

Determining training loads within a periodized programme allows strength coaches to target specific attributes, optimize adaptation and allow for recovery [15]. A common method to determine resistance-training loads known as PBT, prescribes relative submaximal loads from a 1RM. Even though 1RMs are valid, reliable and require no monitoring equipment, they are time consuming when conducted with large groups. Moreover, maximal strength can fluctuate daily when fatigued or significantly increase within a few weeks due to training adaptation [13]. Consequently, training when fatigued, or continued training based on an out-dated 1RM may not optimize the neuromuscular stimuli required to maximize adaptation. For these reasons, alternative methods for prescribing training loads have been established.

For example, RM training requires an athlete to perform a prescribed number of repetitions in a set (e.g. 8-10RM) until concentric muscular failure. Although this method accounts for sessional adjustment of training load, it may require an athlete to perform multiple sets to reach the target RM load. Furthermore, research suggests that RM training sets can reduce the force generating capacity in subsequent training sets and may diminish maximal strength development in well-trained athletes [12, 18, 30]. More recently, adjusting training loads based on an athlete's rating of perceived exertion (RPE) has become an alternative to PBT, since it allows for the modification of sessional loads based on an athlete's perceptual readiness to train [99, 102]. Although RPE-based methods are valid and reliable, they can be problematic since they are subjective and also require a prescribed number of repetitions in a set to be completed until adjustments can be made. Therefore, an approach that uses instantaneous repetition feedback to objectively prescribe training loads could optimize adaptation and avoid training to failure.

Due to advancements in commercially available kinetic and kinematic measuring devices, it is now possible to provide instantaneous feedback during training for numerous variables such as movement velocity. Accordingly, recent literature has explored the use of immediate feedback employing VBT methods to objectively manipulate resistance-training loads within a training session [14, 20, 26, 33]. If an exercise is performed with maximal concentric effort and fatigue ensues, the barbell velocity of the movement will decrease within a set [18, 30]. As greater movement velocities with a given load increase the neuromuscular stimuli and adaptations to strength training [14], decreases in movement velocity can be detrimental. Therefore, VBT can be used to monitor barbell velocity and avoid performing repetitions to concentric muscular failure if the training target is to optimize maximal strength and power development, particularly in well-trained athletes [12].

One VBT approach is characterized by the cessation of a working set if the MV of a repetition falls below a pre-determined velocity loss threshold [21]. For example, Padulo et al. [13] implemented a 20% velocity loss threshold and showed that maintaining at least 80% of MV during training results in greater increases in bench press 1RM compared to RM training. Similarly, Pareja-Blanco et al. [20] also showed that using a 20% velocity loss threshold resulted in similar increases in strength but greater increases in power output compared to a 40% velocity loss threshold. To further elaborate, two variations of the velocity loss threshold method have been introduced [21]. The variable sets velocity loss threshold (VS_{VL}) method includes a fixed training load and total number of repetitions, but allows for an indefinite number of sets, each finishing when a repetition drops below a pre-determined maximum percent velocity loss [33]. This method allows an athlete to spread the total number of repetitions across multiple sets, allowing for greater recovery time, enabling an athlete to perform all of the prescribed repetitions with faster movement velocities. Comparatively, the fixed sets velocity loss threshold (FS_{VL}) method includes a pre-determined training load and number of sets, but does not have a prescribed number of repetitions. This method requires an athlete to perform repetitions in a set until they are no longer able to produce the required velocity.

Importantly, MV and individualised LVPs have been shown to be reliable [49, 50, 103], yet no research has explored the use of the LVP as a method to adjust training load. It is proposed that if velocity targets are not met according to the individualised LVP during a training session then training load can be adjusted to meet these targets [103]. For example if the velocity is lower than the velocity from the individualised LVP, the training load can be reduced. Alternatively, if the velocity output during a training session is faster than the target velocity then the training load can be increased. Previous VBT research has individualised training volume prescription (number of repetitions per set) [20, 26, 33] but notably, no research has used velocity to individualize training load prescription (load-velocity relationship). Additionally, participants within these studies have used a Smith machine and not a large mass free-weight barbell exercise. This is important to discern since free-weight exercises are extensively utilized in practice with most athletes and often require movements in both the vertical and horizontal planes, which may produce different velocity, force and power outputs. Furthermore, no studies have compared VBT to more traditional PBT methods.

Therefore, the objective of this study was to compare the effects of the LVP, FS_{VL} , VS_{VL} and PBT methods on the mechanical capacities of the lower body during a typical strength-oriented training session in a free-weight exercise. Based on the results of previous research [20, 26, 33],

we hypothesized all three VBT training methods would result in greater movement velocities and power outputs, but the LVP and FS_{VL} methods would result in the completion of less work and time under tension compared to a PBT session since it is conceivable that lighter loads (LVP method) or fewer repetitions (FS_{VL} method) would be completed.

METHODS

Participants

Fifteen resistance-trained men participated in this study (age: 25.1 ± 3.9 y, height: 179.7 ± 6.7 cm, body mass: 83.9 ± 10.6 kg) and performed the full depth back squat with a mean knee flexion angle of $121.8 \pm 9.4^\circ$ as measured by a handheld plastic goniometer. Their mean 1RM was 151.3 ± 22.2 kg which was normalized to 1.83 ± 0.29 per kg of body mass (range = 1.55 to 2.43 per kg of body mass). The participants had 6.7 ± 2.2 years of resistance training experience ranging from one to three sessions per week and were free from musculoskeletal injuries. Each participant gave written informed consent prior to volunteering, which was in accordance with the ethical requirements of the Institutional Human Research Ethics Board. The protocols for this study also adhered to The Code of Ethics of the World Medical Association (Declaration of Helsinki).

Experimental Design

A randomized crossover design was chosen where volunteers completed all four conditions. Participants visited the laboratory for a 1RM session, LVP assessment and four randomized strength-oriented training sessions. Participants were afforded 48 h rest following the 1RM and LVP assessments, but 96 h rest between the four testing sessions to allow for sufficient recovery. Experimental sessions included: 1RM-percent-based training (PBT); load-velocity profile (LVP); fixed sets 20% velocity loss threshold (FS_{VL20}); variable sets 20% velocity loss threshold (VS_{VL20}) (Table 3).

Table 3. Description of the experimental sessions.

Group	Load (%1RM)	Sets	Reps	Total Reps	Set Completion
PBT	80%	5	5	25	Forced Completion
LVP	80%; Adjust Load by 5%1RM if set is $\pm 0.06 \text{ m}\cdot\text{s}^{-1}$ LVP@80%	5	5	25	Forced Completion
FS _{VL20}	80%	5	?	?	20% Velocity Decline
VS _{VL20}	80%	?	?	25	20% Velocity Decline

Note: Traditional 1RM-percent-based training (PBT), load-velocity profile (LVP); fixed sets 20% velocity loss threshold (FS_{VL20}), variable sets 20% velocity loss threshold (VS_{VL20}) sessions.

Experimental Procedure

Session One: One-Repetition Maximum (1RM) Assessment

Participants performed all repetitions in a power cage (Fitness Technology, Adelaide, Australia) using a 20kg barbell (Eleiko®; Halmstad, Sweden). Prior to the 1RM assessment, participants performed warm-up procedures consisting of five minutes pedalling on a cycle ergometer (Monark 828E cycle ergometer; Vansbro, Dalarna, Sweden) at 60-revolutions per minute and 60W, three minutes of dynamic stretching and 10 full depth bodyweight squats. Participants then commenced the 1RM assessment, comprising sets estimated at 20% (3-repetitions), 40% (3-repetitions), 60% (3-repetitions), 80% (1-repetition), and 90% 1RM (1-repetition) [66]. This was then followed by the first 1RM attempt with five 1RM attempts permitted. After successful 1RM attempts, barbell load was increased in consultation with the participant between 0.5 and 2.5 kg. The last successful lift with correct technique and full depth was classified as the 1RM load. Two minutes passive rest was allocated between all warm-up sets, but three minutes between 1RM attempts. Participants were required to keep the barbell in constant contact with the superior aspect of the trapezius muscle and their feet with ground contact at all times. The eccentric phase of the squat was performed in a controlled manner but once full knee flexion was achieved, the concentric phase was completed as fast as possible.

Session Two: Load-Velocity Profile (LVP) Assessment

Recent research has reported that MV of the free-weight back squat is reliable at 20%, 40%, 60%, 80% and 90% 1RM but not 100% 1RM [103]. Therefore, it was recommended that individualised LVPs should be developed using MV from 20% to 90% 1RM. Consequently, participants came to the laboratory and performed the same cycling and dynamic warm-up protocols as session one, followed by back squat sets using 20% (3-repetitions), 40% (3-repetitions), 60% (3-repetitions), 80% (1-repetition) and 90% 1RM (1-repetition) with two minutes passive recovery given between sets. The 1RM assessment (session one) allowed for accurate relative 1RM loads to be lifted for the LVP assessment. For sets that included more than one repetition (i.e. 20%, 40%, and 60% 1RM), the repetition with the fastest MV was utilized for the LVP [23]. The individualised LVP's were constructed by plotting MV against relative load and then applying a line of best fit to the data (Microsoft Excel 2016, Microsoft, Redmond, Washington, USA). A linear regression equation was then calculated and used to modify the training load in the LVP experimental session.

Sessions Three, Four, Five, and Six: Experimental Sessions

At the commencement of the randomized sessions, participants performed the identical cycling, dynamic stretching and bodyweight squat warm-up protocols to sessions one and two. Participants then performed warm-up squat sets with maximal concentric effort using 20% (3-repetitions), 40% (3-repetitions), 60% (3-repetitions), and 80% 1RM (1-repetition) prior to all experimental testing sessions. Following these squat sets, two minutes rest was given before the commencement of an experimental session. The rest period between each training set was two minutes and the time between repetitions within a set was approximately two seconds for the VBT sessions as well as the PBT session. All squat repetitions in every session were performed with a self-selected, controlled eccentric velocity to full depth (knee angle = $122.5 \pm 8.3^\circ$, squat depth = 707 ± 57 mm), which did not differ between sets or sessions ($p > 0.05$). The concentric phase for every repetition in all sessions was performed with maximal effort immediately after the eccentric phase. In addition, all participants were verbally encouraged to perform each repetition with maximal effort but no participant was provided or able to observe any velocity feedback in any session. However, participants were instructed to terminate a set if velocity targets were not met (FS_{VL20} or VS_{VL20} session) and the load was adjusted if velocity targets were not met (LVP session), indicating that the subjects could figure out whether their velocity of the previous set was above or below the threshold.

The PBT session involved five sets of five repetitions (25-repetitions) using 80% 1RM. During this protocol, MV was measured, but did not dictate changes in the external load, number of sets, or number of repetitions.

For the LVP training session, participants performed five sets of five repetitions, but with a load that (when performed with maximal intent) achieved an individualised target velocity that was established from the individual's LVP regression equation at 80% 1RM (established in session two). If the difference in MV during the warm-up at 80% 1RM was $\pm 0.06 \text{ m}\cdot\text{s}^{-1}$ compared to the target velocity at 80% 1RM according to the individualised LVP (as reported by Banyard et al. [103]), the first set's training load was adjusted by $\pm 5\%$ 1RM. Otherwise, the relative load for the initial training set was kept at 80% 1RM. Once a set of five repetitions was completed, the load for the subsequent set could be adjusted by $\pm 5\%$ 1RM if the average of the MV for the five repetitions of the previous set was $\pm 0.06 \text{ m}\cdot\text{s}^{-1}$ the target velocity at 80% 1RM according to the LVP. In this manner, all participants completed 25-repetitions, but the load of subsequent sets could be adjusted according to the MV of the preceding set's repetitions.

The FS_{VL20} session was similar to the PBT session where individuals completed five sets using 80% 1RM. However, sets were terminated once the MV of a repetition dropped below 20% of the threshold velocity or when five repetitions in the set were completed at or above the threshold velocity. When a set was terminated the participant was instructed to cease from squatting and rack the barbell. In this manner, it was possible for participants to complete all 25-repetitions, or fewer.

In the VS_{VL20} session, participants completed 25-repetitions in total, but they performed as many repetitions in a row as possible until the threshold velocity loss (20%) was exceeded. In this manner, participants completed 25-repetitions in as few sets as possible. The 20% velocity loss threshold for the FS_{VL20} and VS_{VL20} sessions was determined from the MV of the single repetition performed at 80% 1RM in the experimental protocol warm-up.

Data Acquisition

All kinetic and kinematic data were collected during the concentric phase of the squat unless noted otherwise using similar methodology to previous research [19, 67, 94]. This included MV and PV measures that were captured from four LTs (Celesco PT5A-250; Chatsworth, California, USA) mounted to the top of the power cage with two positioned in an anterior and posterior location on both the left and right side of the barbell. The eccentric phase of each repetition commenced at zero displacement (standing) and was completed at maximal displacement (greatest

descent) whereas the concentric phase began at maximal displacement and terminated at zero displacement. Time under tension (TUT) was calculated by adding the time spent during the eccentric (ETUT) and concentric (CTUT) phases of each repetition. The sum of the time under tension for the respective phases was also calculated for the session (sETUT, sCTUT and sTUT) (Figure 27). MF and PF were acquired from the quantification of ground reaction forces with the use of a force plate (AMTI-BP6001200, Watertown, Massachusetts, USA). MP was calculated as the average and PP measures were calculated from the product of force and bar velocity. Mean total work (MW) and total session work (TW) were calculated by integrating the area under the force-displacement curve during the eccentric and concentric phases of each repetition [70]. The sum of the total session load (TL) and mean session load (ML) were also established. The LT and force plate data were collected through a BNC-2090 interface box with an analogue-to-digital card (NI-6014; National Instruments, Austin, Texas, USA) and sampled at 1000Hz. All data were collected and analysed using a customized LabVIEW program (National Instruments, Version 14.0). All signals were filtered with a 4th order-low pass Butterworth filter with a cut-off frequency of 50 Hz. The total tension on the barbell as a result of the transducer attachments (23.0 N) was accounted for in all calculations. Mean values of velocity, force and power were determined as the average data collected during the concentric phase of the repetition. Contrastingly, peak values of velocity, force and power were determined as the maximum value during the concentric phase of the lift. MV, PV, MF, PF, MP, PP, ML, MW, ML, ETUT, CTUT, and TUT were calculated as the average of all repetitions for each individual within a session (Figure 23 – 27), whereas TL, TW, sETUT, sCTUT and sTUT were calculated by totalling the respective data from all repetitions for each individual in a session (Figure 26 and 27).

Statistical Analyses

For all dependent variables a repeated measures ANOVA was used to identify any differences between the four experimental protocols with a type-I error rate set at $\alpha \leq 0.05$. Holm's Sequential Bonferroni post hoc comparisons were used when appropriate [104]. ES ($\pm 95\%$ confidence intervals) were calculated using Cohen's *d* which was interpreted as trivial (≤ 0.2), small (0.20 – 0.60), moderate (0.60 – 1.20), large (1.2 – 2.0) or very large (≥ 2.0) [75]. Data analyses were performed using a statistical software package (SPSS version 22.0, IBM, Armonk, NY, USA). Data are reported as mean \pm SD unless stated otherwise.

RESULTS

The load, number of sets, number of repetitions per set, and total session repetitions for each experimental session is shown in Table 4. There was no adjustment of training load for the first set of the LVP session for any participants, indicating the MV at 80% 1RM in the warm-up was within the smallest detectable difference range ($\pm 0.06 \text{ m}\cdot\text{s}^{-1}$ at 80% 1RM). Significantly fewer repetitions were performed during FS_{VL20} (23.6 ± 2.0 repetitions) compared to all other sessions (25-repetitions) (Table 4). During VS_{VL20}, participants completed the 25 repetitions in 4.3 ± 0.9 sets (range = 3 – 6 sets) (Table 4). Session time was significantly shorter during VS_{VL20} ($9:02 \pm 1:55$ min) than PBT ($10:36 \pm 0:19$ min), LVP ($10:34 \pm 0:22$ min), and FS_{VL20} ($10:21 \pm 0:55$ min). Compared to PBT (MV: $0.53 \pm 0.06 \text{ m}\cdot\text{s}^{-1}$; PV: $1.04 \pm 0.04 \text{ m}\cdot\text{s}^{-1}$), MV and PV were significantly faster during LVP (MV: $0.60 \pm 0.06 \text{ m}\cdot\text{s}^{-1}$, ES = 1.05; PV: $1.09 \pm 0.04 \text{ m}\cdot\text{s}^{-1}$, ES = 1.12) and FS_{VL20} (MV: $0.58 \pm 0.05 \text{ m}\cdot\text{s}^{-1}$, ES = 0.81; PV: $1.10 \pm 0.06 \text{ m}\cdot\text{s}^{-1}$, ES = 0.98) (Figure 23). TUT and CTUT was significantly less during LVP compared to PBT (Figure 27). Significant differences were also observed between PBT and FS_{VL20} for sTUT and sCTUT (Figure 27). There were no significant differences between any of the sessions for all other variables.

Table 4. Mean \pm SD description of each experimental session.

Session	Load (kg)	Sets	Repetitions per Set						Total Repetitions
			1	2	3	4	5	6	
PBT	122.4 \pm 17.8	5	5	5	5	5	5	-	25
LVP	120.5 \pm 17.2	5	5	5	5	5	5	-	25
FS _{VL20}	122.4 \pm 17.8	5	5	5	4.8 \pm 0.4	4.5 \pm 0.7	4.2 \pm 0.9	-	23.6 \pm 2.0
VS _{VL20}	122.4 \pm 17.8	4.3 \pm 0.9	7.9 \pm 1.9	6.9 \pm 1.7	5.5 \pm 0.9	3.0 \pm 1.8	1.2 \pm 1.8	0.5 \pm 1.8	25

Note: Traditional 1RM-percent-based training (PBT), load-velocity profile (LVP); fixed sets 20% velocity loss threshold (FS_{VL20}); variable sets 20% velocity loss threshold (VS_{VL20}).

DISCUSSION

The major findings from the present study were that participants could sustain significantly faster MV and PV for repetitions performed during LVP and FS_{VL20} compared to PBT. In addition, the same two VBT methods allowed participants to perform repetitions with significantly less mechanical stress (CTUT, TUT, sCTUT, sTUT) while still completing similar amounts of work (MW, TW) to PBT. The FS_{VL20} session also resulted in significantly fewer repetitions than all other methods. Furthermore, no significant differences were observed for measurements of force (MF, PF), power (MP, PP) and training load lifted (ML, TL) between any of the experimental sessions. Consequently, in a single session, the LVP and FS_{VL20} methods appear to be more

favourable than PBT for athletes performing strength-oriented training due to faster movement velocities, less mechanical stress but still enduring similar measures of force, power, work and training load.

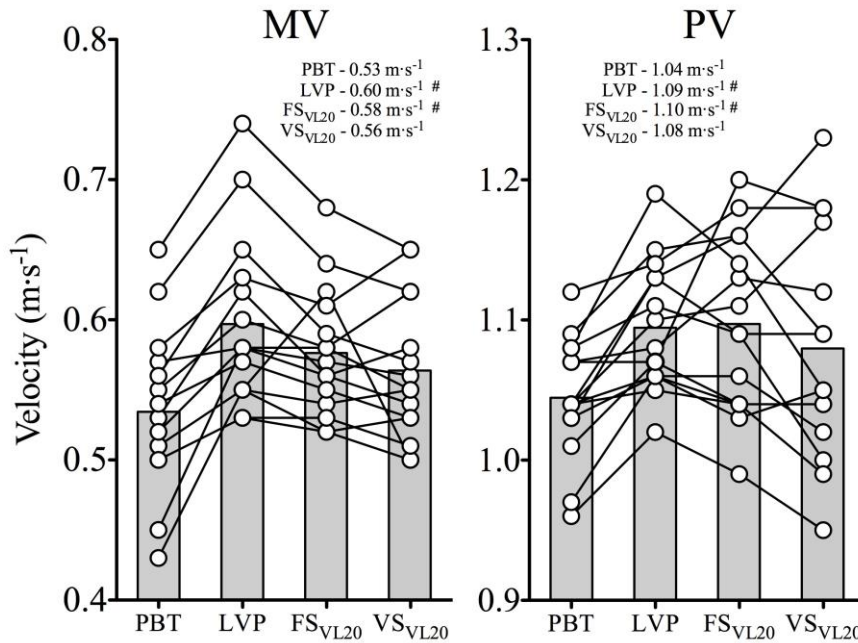


Figure 23. Individual variation of mean repetition values of mean velocity (MV) and peak velocity (PV) for the 1RM-percent-based training (PBT), load-velocity profile (LVP), fixed sets 20% velocity loss threshold (FS_{VL20}), and variable sets 20% velocity loss threshold (VS_{VL20}) sessions. The shaded bars indicate the group mean, and the figure legend contains the numerical group velocities for the experimental sessions. #Significant difference between an experimental session and PBT.

The significantly higher MV (ES = 1.05) and PV (ES = 1.12) observed during the LVP session compared to the PBT session can be attributed to subtle decreases in load (~5% 1RM) between sets, yet the total load lifted was not significantly less. By comparison, the significantly higher movement velocity observed during FS_{VL20} compared to PBT (MV: ES = 0.81; PV: ES = 0.98) were due to the strict 20% velocity loss threshold which resulted in the completion of significantly fewer repetitions (23.6 ± 2.0 vs. 25). It is difficult to determine the “optimal” resistance-training dose to maximise strength and power development since there are so many factors that influence adaptation. However, research investigating this phenomenon in the back squat and weightlifting exercises have established that performing a moderate volume of repetitions could be more beneficial than performing an unnecessarily high number of repetitions (high volume) [105]. For example, Pareja-Blanco et al. [26] had 16 resistance trained professional

male soccer players perform six weeks (18 sessions, ranging from ~50 to ~70% 1RM) of back squat training and were evenly assigned into two groups, which differed by a 15% or 30% velocity loss threshold in each training set. Subsequently, the 15% velocity loss group trained with significantly fewer repetitions (total repetitions: 251.2 ± 55.4 vs. 414.6 ± 124.9 ; mean repetitions/set: 6.0 ± 0.9 vs. 10.5 ± 1.9) and at faster movement velocities (AV: $0.91 \pm 0.01 \text{ m}\cdot\text{s}^{-1}$ vs. $0.84 \pm 0.02 \text{ m}\cdot\text{s}^{-1}$), yet had significantly greater increases in maximal strength (estimated 1RM squat) and power output (CMJ height) compared to the 30% velocity loss group. In light of these findings, coaches can monitor velocity and employ velocity loss thresholds so that immediate feedback can help inform accurate training volume decisions where limiting repetitions performed at slower movement velocities and maximizing the number of repetitions performed at faster velocities may produce greater increases in strength and power adaptations over time.

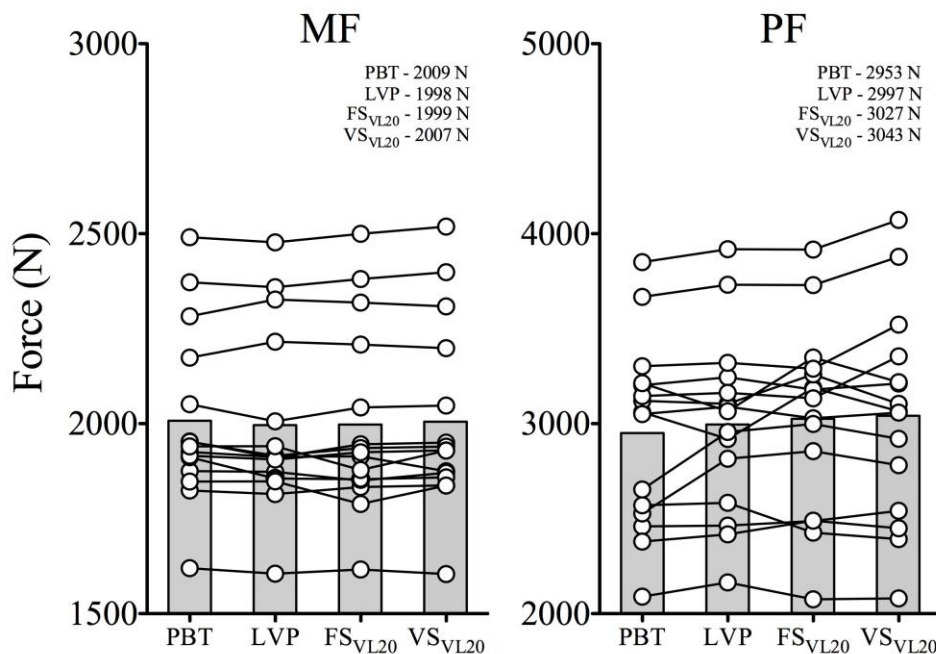


Figure 24. Individual variation of mean repetition values of mean force (MF) and peak force (PF) for the 1RM-percent-based training (PBT), load-velocity profile (LVP), fixed sets 20% velocity loss threshold (FS_{VL20}), and variable sets 20% velocity loss threshold (VS_{VL20}) sessions. The shaded bars indicate the group mean, and the figure legend contains the numerical group force values for the experimental sessions.

The LVP and FS_{VL20} sessions also resulted in significantly less mechanical stress compared to PBT session, evidenced by less CTUT (Figure 27). In accordance with the load-velocity relationship, the lower mechanical stress observed during the LVP session was a consequence of the subtle training load reduction (ML and TL) which was not statistically different to the PBT

session (ES = 0.00 – 0.34). Contrastingly, the significantly lower mechanical stress (sCTUT and sTUT) during FS_{VL20} compared to PBT was due to the completion of fewer repetitions (ES = 1.01). A potential limitation of reduced mechanical stress associated with the LVP and FS_{VL20} sessions is the reduced training stimulus required to maximize muscle hypertrophy [106]. For example, Pareja-Blanco et al. [20] had 22 resistance-trained men perform eight weeks (16-sessions, ranging from ~68 to ~85% 1RM) of the back squat exercise on a Smith machine (back squat 1RM: 106.2 ± 13.0kg, 1RM to body mass ratio: 1.41 ± 0.19) with the training groups only differing by the allowed velocity loss threshold in each set (20% vs. 40%). The 40% velocity loss-training group performed significantly more repetitions (total repetitions: 310.5 ± 42.0 vs. 185.9 ± 22.2; mean repetitions/set: 6.5 ± 0.9 vs. 3.9 ± 0.5) and had significantly greater hypertrophy of Vastus Lateralis and Intermedius muscles (9.0% increase in muscle volume) compared to the 20% velocity loss group (3.4% increase) which was not surprising since they completed significantly more work by performing 40% more repetitions [106]. These findings indicate that completing fewer repetitions or reducing mechanical stress would likely result in less muscular development, suggesting that the FS_{VL20} method and parameters employed in the present study may not be beneficial for hypertrophic-oriented training. However, Pareja-Blanco et al. [20] also found that the 20% velocity loss training group maintained significantly faster movement velocities (MV: 0.69 ± 0.02m·s⁻¹ vs. 0.58 ± 0.03m·s⁻¹), had similar increases in maximal strength (18.0% vs. 13.4%) and had significantly greater improvements in CMJ height (9.5% vs. 3.5%) compared to the 40% velocity loss group. Therefore, although more repetitions maximized muscle hypertrophy, more repetitions did not lead to additional strength gains and may not be advantageous for adaptations associated with explosive, powerful movements.

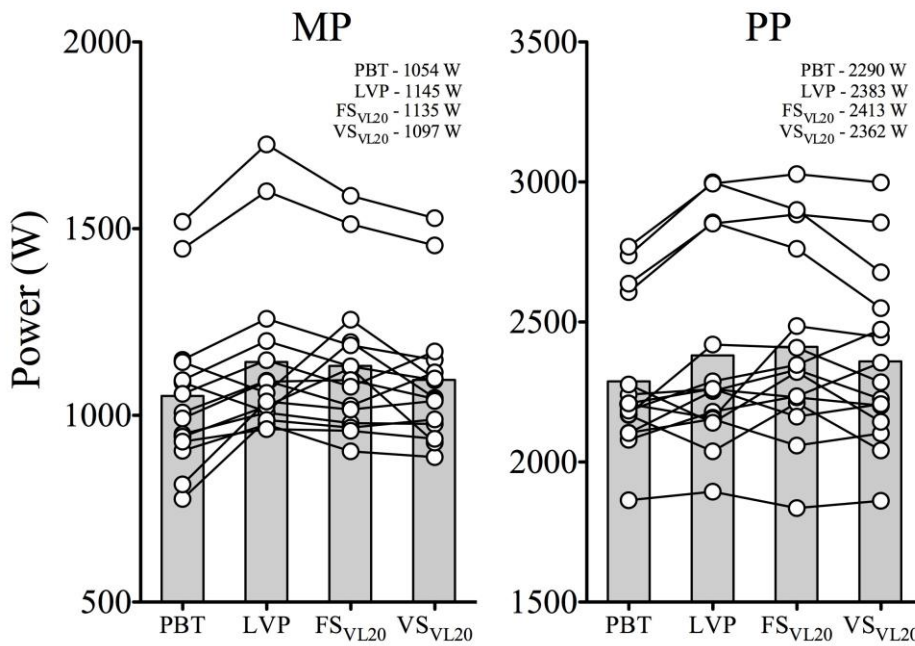


Figure 25. Individual variation of mean repetition values of mean power (MP) and peak power (PP) for the 1RM-percent-based training (PBT), load-velocity profile (LVP), fixed sets 20% velocity loss threshold (FS_{VL20}), and variable sets 20% velocity loss threshold (VS_{VL20}) sessions. The shaded bars indicate the group mean, and the figure legend contains the numerical group power values for the experimental sessions.

Although the present study did not investigate the chronic effects of these protocols, it is possible to hypothesize the rationale for adopting the LVP, FS_{VL20} and VS_{VL20} training sessions for strength and power development in a strength-oriented training cycle. The phosphagen system in the human body is the predominant energy system responsible for explosive movements desired to maximize increases in strength and power output [15, 107]. This energy system typically lasts for up to 10 seconds of maximal effort and when depleted, coincides with rapid decreases in movement velocity [107]. If energy stores are depleted without sufficient recovery, it is speculated that training under energy depletion and excessive velocity loss could induce adaptations towards slower, more fatigue resistant fibre types. This is particularly important for athletes whose training goal is primarily focused on explosive force production associated with strength and power training and not on maximizing muscle hypertrophy. In addition, increased muscular development could be problematic for athletes required to maintain a specific body mass and furthermore, the greater mechanical stress which does not lead to greater increases in strength may cause unnecessary fatigue and prolong recovery time. Therefore, in order to optimize strength and power development, a coach can employ PBT and prescribe a lower number of repetitions per set, or

VBT (e.g. LVP, FS_{VL20} and VS_{VL20}) with objective repetition velocity feedback to reduce the amount of velocity loss in a training session so that the required energy system and preferential targeting of Type IIX fibers can be utilized to maximize strength and power development [20, 21].

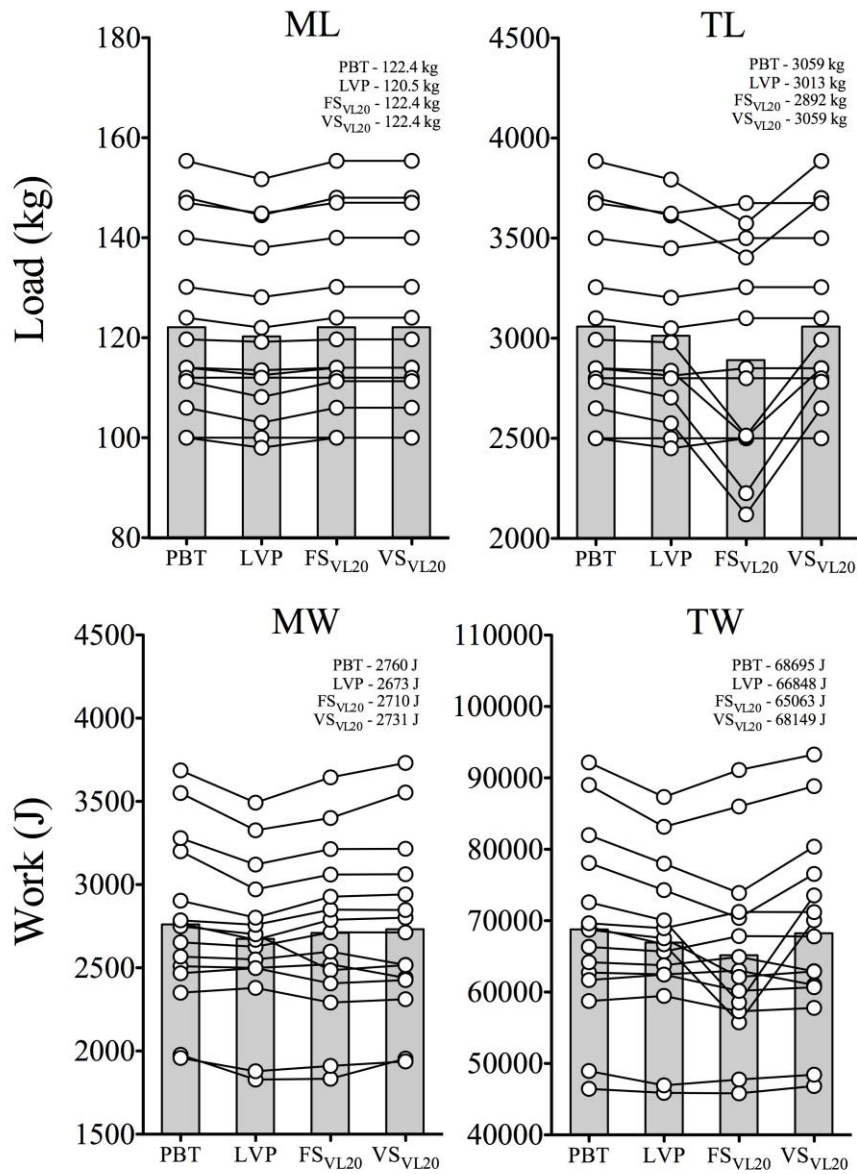


Figure 26. Individual variation during the 1RM-percent-based training (PBT), load-velocity profile (LVP), fixed sets 20% velocity loss threshold (FS_{VL20}), and variable sets 20% velocity loss threshold (VS_{VL20}) sessions for values of mean repetition load (ML), mean repetition work (MW), total session load (TL) and total session work (TW), The shaded bars indicate the group mean, and the figure legend contains the numerical mean group values for the experimental sessions.

Importantly, participants completed the VS_{VL20} session in a significantly shorter amount of time (~90 seconds shorter) compared to the other sessions, yet there were no significant differences in MV, PV, MF, PF, MP, PP, ML, TL, MW, TW, ETUT, CTUT, or TUT between VS_{VL20} and all other sessions. This additional 90seconds per exercise (e.g. ~9 minutes for 6 exercises) could potentially be reallocated to another training modality or an additional exercise: something that could be valuable during time-restricted strength sessions. Although some may argue that it takes more time to implement VBT compared to PBT due to setting up the devices, these steps can be done by the strength and conditioning staff before training, which does not increase an athlete's training time. However, in the present study there were two participants who took longer (6 sets) than the five sets prescribed in the other experimental sessions. Even though VS_{VL20} required participants to complete as many quality (highest possible velocity output against a given load) repetitions in as few sets as possible, the VS_{VL20} training method can allow for flexibility in determining the optimal repetition scheme to accommodate daily fluctuations in performance [25]. As such, the VS_{VL20} method allowed these two participants to complete fewer repetitions per set, allowing for more recovery time to complete the prescribed total number of repetitions with higher velocity outputs. By contrast, VS_{VL20} also allowed the other 13 participants to complete 25 repetitions in fewer sets than the other experimental methods. Therefore, VS_{VL20} could be preferred over PBT since it integrates a more objective, Individualised approach based upon an athlete's readiness to train.

The inclusion of VBT methods over PBT may raise some potential limitations with its use in large groups. For example, all VBT methods require specialized equipment to accurately monitor movement velocity, and an athlete or coach must modify the training load or repetition volume based on the velocity outputs. Additionally, the LVP method requires individualised mathematical calculations, but these are no more difficult than the calculations required for PBT load prescription. Nevertheless, monitoring devices are becoming more affordable and the latest devices now provide instantaneous feedback making it simple to employ the VBT methods from the present study. For instance, velocity-monitoring tools can report the average MV of a set, making it easy to compare with a prescribed target velocity (LVP method). Furthermore, some devices even allow for a specified velocity loss threshold to be set prior to training (e.g. FS_{VL20} and VS_{VL20}), expediting their use during training.

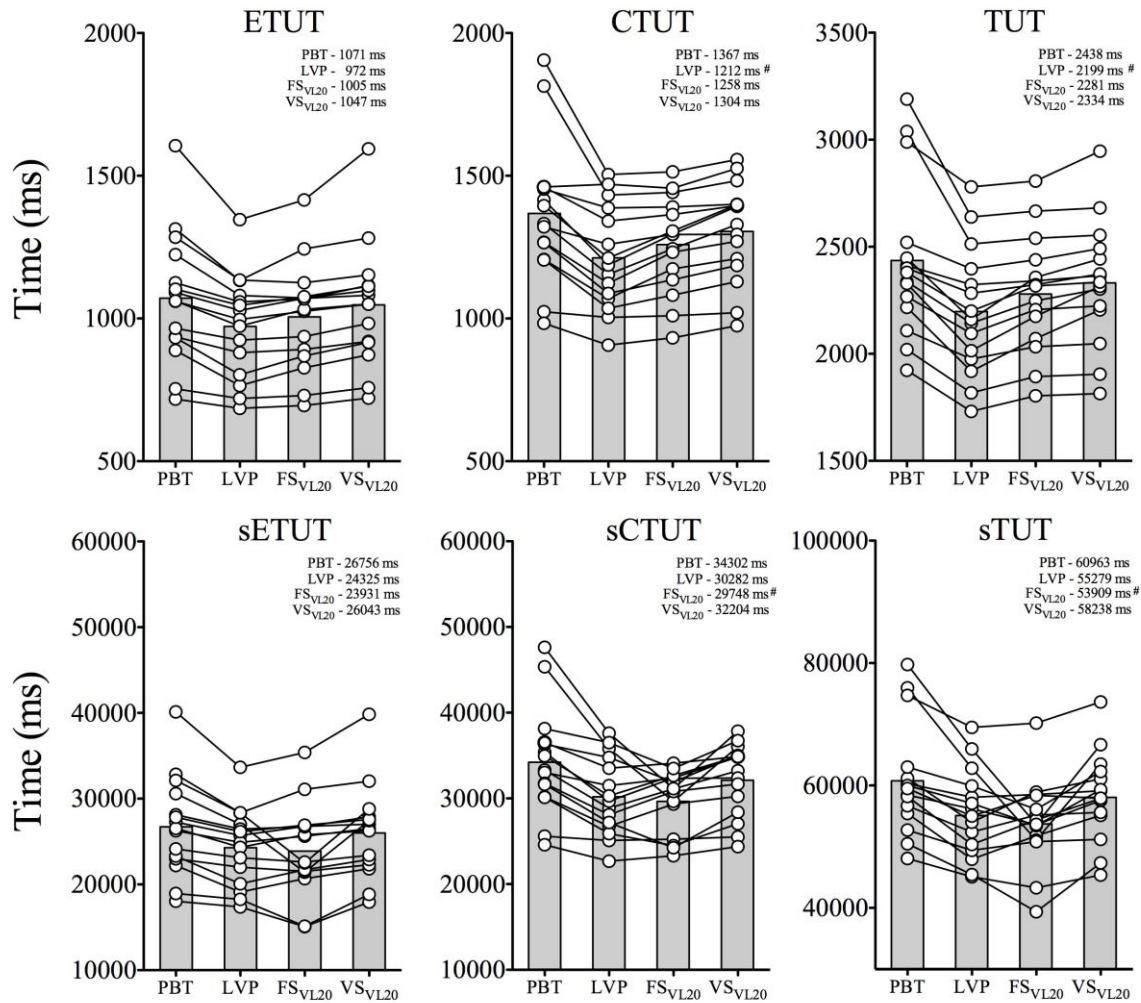


Figure 27. Individual variation during the 1RM-percent-based training (PBT), load-velocity profile (LVP), fixed sets 20% velocity loss threshold (FS_{VL20}), and variable sets 20% velocity loss threshold (VS_{VL20}) sessions for values of mean eccentric time under tension (ETUT), mean concentric time under tension (CTUT), mean total time under tension (TUT), total session eccentric time under tension (sETUT), total session concentric time under tension (sCTUT) and total session time under tension (sTUT). The shaded bars indicate the group mean, and the figure legend contains the numerical mean group values for the experimental sessions. # Significant difference between and experimental session and PBT.

CONCLUSIONS

The present study revealed that individuals employing the LVP and FS_{VL20} VBT methods could reduce mechanical stress and maintain significantly faster movement velocities during a training session compared to PBT. In addition, VS_{VL20} elicited similar training responses to the other experimental sessions, yet was completed in a significantly shorter time. Therefore, VS_{VL20} could be viewed as a viable training method for athletes who are pressured for time. As a

consequence, the use of VBT allows one to modify training, accounting for the current state of the neuromuscular system. Results from the present study show that LVP and FS_{VL20} VBT methods can be employed in a strength-oriented training phase to diminish fatigue-induced decreases in movement velocity that can occur in training based on 1RM percentages.

PRACTICAL APPLICATIONS

The present study shows that the VBT methods employed in the present study may serve as an alternative to more traditional strength-oriented PBT sessions. Specifically, the LVP and FS_{VL20} methods permitted individuals to perform repetitions with faster velocities across the entire training session compared to PBT, while performing repetitions with less mechanical stress but maintaining similar measures of force and power output. Alternatively, the VS_{VL20} method had similar kinetic and kinematic data compared to PBT and the other VBT methods but could be completed in a significantly shorter time period which could benefit individuals with time constraints. However, it must also be acknowledged that the use of VBT methods requires time to set up the equipment prior to training which is not required for PBT sessions.

CHAPTER 7: STUDY 5

THE EFFECTS ON STRENGTH AND POWER ADAPTATIONS FOLLOWING SIX WEEKS OF VELOCITY- BASED TRAINING OR 1RM-PERCENT-BASED TRAINING

Banyard HG, Tufano JJ, Weakley JS, & Nosaka K.

ABSTRACT

We compared the effects of VBT and PBT on changes in strength, power and sprint times when groups were matched for sets and repetitions but differed in training load prescription. Twenty-four resistance-trained males performed six weeks of full depth free-weight back squats three times per week in a daily undulating format. PBT lifted with relative loads varying from 59% – 85% 1RM whereas VBT trained with loads that could be adjusted to achieve a target velocity from an individualised LVP that corresponded with 59% – 85% 1RM. Pre- and post-training assessments included 1RM, 30% 1RM CMJ, 20m sprint, and 505 change of direction test (COD). VBT performed faster repetitions during training ($p < 0.05$, $MV = 0.76 \text{ m}\cdot\text{s}^{-1}$ vs. $0.66 \text{ m}\cdot\text{s}^{-1}$) that were perceived as less difficult ($p < 0.05$, rating of perceived exertion = 5.1 vs. 6.0), and utilized marginally lower training loads ($p < 0.05$, $\sim 1.7\%$ 1RM) compared to PBT. VBT and PBT groups significantly improved 1RM (VBT: 11.3% vs. PBT: 12.5%), CMJ (7.4% vs. 6.0%), 20m sprint (-1.9% vs. -0.9%), and COD (-5.4% vs. -3.6%), respectively. No significant differences were observed between groups for any testing assessment but *likely* favourable training effects were observed in 1RM for PBT, whilst VBT was *likely* favourable for 5m sprint, and *possibly* favourable for 10m sprint, and COD. Both training methods are similarly effective; however, PBT may provide a slight 1RM strength advantage whilst VBT may be preferred by some individuals since it permits faster training velocities, is perceived as less difficult, and is a more objective method for adjusting training load to account for individual differences in the rate of training adaptation.

INTRODUCTION

Traditional PBT involves prescribing submaximal loads calculated from a 1RM assessment. As this method is quite simple, strength and conditioning coaches can utilise PBT methods to periodise training load and volume to accommodate for recovery and improve physical abilities critical to sports performance [15]. Even though this programming strategy is practical and can be managed with relative ease when training a large team of athletes, it does not account for physical and psychological stressors that can affect an individual's day-to-day performance [25]. Recently it has been shown that individualising sessional training load can help further optimise the neuromuscular stimuli required to maximise training adaptation [102]. For example, Helms et al. [102] et al. found that using an athlete's RPE to prescribe training load may further enhance maximal strength gains compared to PBT methods. Even though RPE-based methods can be used to modify training load and quantify the perceived difficulty of resistance training sessions, the method is subjective. Therefore, more precise objective methods to monitor and prescribe individualised sessional training loads may be of particular interest to strength and conditioning professionals.

Recent advancements in commercially available technology (e.g. LTs) have meant that immediate kinetic and kinematic outputs can be provided while resistance training. Notably, velocity data can be used to objectively manipulate resistance training load and volume within a training session depending on how an athlete is performing on that day (i.e. VBT) [108]. There are three distinct benefits of monitoring velocity during resistance training. Firstly, instantaneous velocity feedback can motivate an individual to maintain maximum effort when exercising [109]. Maximal concentric effort is critical to maintaining training intensity and adaptation, with greater force output [27, 28, 110, 111] and a recruitment of Type II muscle fibres [29] observed when compared to submaximal concentric muscle actions [13, 14]. Secondly, monitoring exercise velocity can assist in the identification of velocity ranges/targets and corresponding training loads that can enhance training specificity [51]. Thirdly, due to the stability of the load-velocity relationship [49, 103], any fluctuations in velocity beyond the normal variation observed between training sessions is likely to reflect acute or chronic fatigue or gains in strength [31, 108]. For these reasons, monitoring velocity during resistance training sessions may be useful when aiming to tailor training prescriptions individually.

Previous VBT research has explored the use of monitoring velocity to modify training volume (number of repetitions per set) by terminating a set once the repetition velocity drops below a specified velocity loss threshold, which is usually conveyed as a percent loss in velocity

from the fastest repetition in the first set [20, 26]. This VBT method mitigates undue fatigue and enables repetitions to be performed with greater velocity and force outputs, which can further enhance strength and power adaptations [12]. However, this method may decrease total training volume, which may be unwarranted. Therefore, alternative VBT methods may allow for a better maintenance of training volume while also minimizing acute fatigue.

In contrast to the threshold-based VBT approach that adjusts the number of repetitions performed within each set, a comparatively novel VBT approach involves adjusting training loads to achieve a certain number of repetitions at a target velocity that is established from an individualised LVP regression equation. This LVP-VBT method is based on research that shows that velocity can accurately determine a %1RM value throughout the entire load-velocity relationship [31, 51]. As a result, coaches can prescribe sessional target velocities and modify their athletes' training load if the velocity targets are not met according to their individualised LVP. Since this VBT method is objective and able to account for day-to-day variation in individual performance, it may allow coaches to further individualize and optimize training compared to PBT without decreasing the number of repetitions performed as occurs during threshold-based VBT methods.

To date, no study has investigated the training effects of the LVP-VBT method compared to a well-planned (i.e. not to repetitions failure) periodised PBT program. To determine the effects of modifying training load to achieve target velocities, the aim of this study was to compare the changes in strength, power, sprint times and perceived training difficulty between the LVP-VBT and PBT methods. The individualised nature of the LVP-VBT method led us to hypothesize that this training method would result in greater adaptations compared to PBT methods.

METHODS

Participants

Twenty-four resistance-trained males were recruited for this study. The subject's descriptive characteristics are provided in Table 5. To be included as a participant, the men must have been free from injury or illness, have a minimum 1RM full-depth back squat of at least 1.5 times body mass, and been performing the back squat for at least two years with a frequency of at least one squat training session per week for the last six months. All participants read the information letter and signed an informed consent form. The university's ethical review board granted ethical approval for the present study.

Table 5. Descriptive characteristics of participants in the VBT and PBT groups.

	VBT (n = 12)	PBT (n = 12)
Age (y)	25.5 ± 5.0	26.2 ± 5.1
Height (cm)	180.7 ± 8.5	181.4 ± 7.4
Body Mass (kg)	84.7 ± 9.5	84.2 ± 7.7
1RM/Body Mass (kg.kg)	1.61 ± 0.17	1.60 ± 0.15

Experimental Design

The duration of the entire study lasted eight weeks with a week of pre- and post-measures testing conducted before and after six weeks of full-depth, free-weight back squat training (Figure 28). Briefly, week one consisted of four sessions with 24 hours separating each session. These included a familiarization session, 1RM assessment, LVP assessment, and power/speed testing session. All of these sessions were repeated during week eight with the exception of the familiarization session.

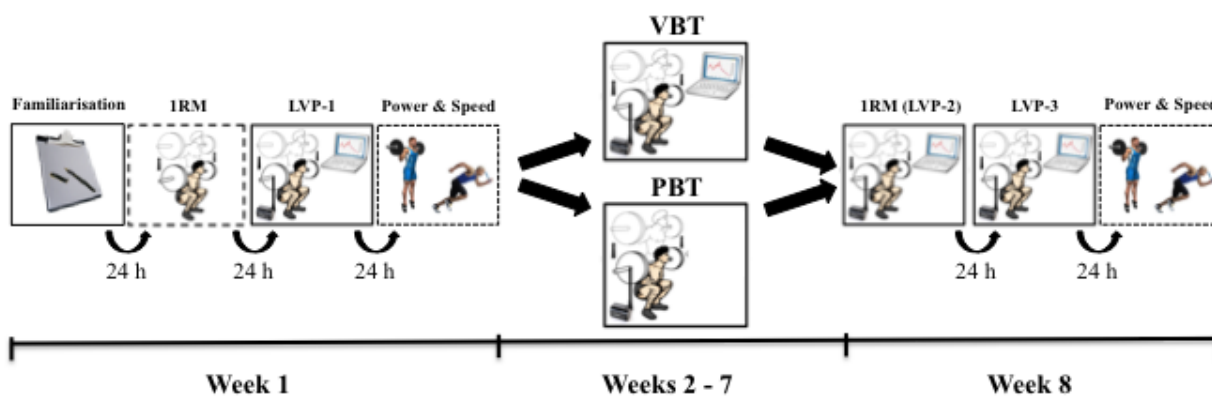


Figure 28. Overall experimental study design timeline.

The groups were counterbalanced using the participant's pre-test 1RM then assigned into either the VBT (n = 12) or PBT (n = 12) group. For the squat training sessions, participants trained three times a week, on non-consecutive days, for a total 18 sessions. Except for the loading prescription, all aspects of the training study were identical between groups including the rest periods (two minutes between sets) and set and repetition configurations (five sets of five repetitions). This was due to the fact that we only wanted to observe the effect of modifying training loads to achieve target velocities and establish whether differences in this VBT method and PBT were apparent. A summary of the resistance training loads for the two groups can be seen

in Figure 30A. For the PBT group, each week of training included training loads that descended from session to session during the week (heaviest to lightest) but ascended from week to week, except for the final week of training where the same loads were prescribed as week one (Figure 30A). This was done to taper for the post-testing assessments. The VBT program was very similar, but the target velocities ascended from session to session during the week and descended from week to week, with the final week of training having the same target velocities as week one (Figure 30).

Experimental Procedure

Familiarisation Session

During this session, the participants entered the laboratory, read through the information letter, and then filled out a medical questionnaire and informed consent form. They then had their age, height and body mass recorded before proceeding with a light warm-up followed by three barbell CMJ's and five barbell squat repetitions, with three minutes rest allocated between the two exercises. Despite the participants experience in these exercises, the CMJ and squat repetitions were performed to ensure the strict technique requirements of the study were adhered to. A 20 minute rest period was then followed by another light dynamic warm-up, three 20m sprint efforts and six 505-change of direction efforts (three efforts at turning with each leg). After the familiarization session, all participants met the technical criteria and were allowed to continue in the study.

One-Repetition Maximum (1RM) Assessment

Participants performed all repetitions in a power cage (Fitness Technology, Adelaide, Australia) using a 20kg barbell (Eleiko®; Halmstad, Sweden). One LT (GymAware Power Tool, Kinetic Performance Technologies, Canberra, Australia) was attached 65 cm right of barbell centre to collect MV data for all squat repetitions in every session [38, 94]. Prior to the 1RM assessment, participants performed a standardized warm-up consisting of five minutes pedalling on a cycle ergometer (Monark 828E cycle ergometer; Vansbro, Dalarna, Sweden) at 60 revolutions per minute and 60 Watts, three minutes of dynamic stretching and 10 full depth bodyweight squats performed with maximal concentric effort. Participants then commenced the 1RM assessment, comprising of sets estimated at 20% (3-repetitions), 40% (3-repetitions), 60% (3-repetitions), 80% (1-repetition), and 90% 1RM (1-repetition) [66]. This was then followed by the first 1RM attempt. Following successful 1RM attempts, barbell load was increased between 0.5 and 5 kg in

consultation with the participant. A maximum of five 1RM attempts were permitted and the last successful lift with correct technique and full depth was classified as the participant's 1RM. Two minutes of passive rest was allocated between all warm-up sets and three minutes between 1RM attempts. Participants were required to keep the barbell on the superior aspect of the trapezius muscle and their feet with ground contact at all times. The eccentric phase of the squat was performed in a controlled manner but once full knee flexion was achieved, the concentric phase was completed as fast as possible with verbal encouragement provided by the chief investigator. This same squat technique was used for every squat repetition performed throughout the study. The warm-up loads (20% – 90% 1RM) lifted during the post-testing 1RM session were based off the pre-testing 1RM load.

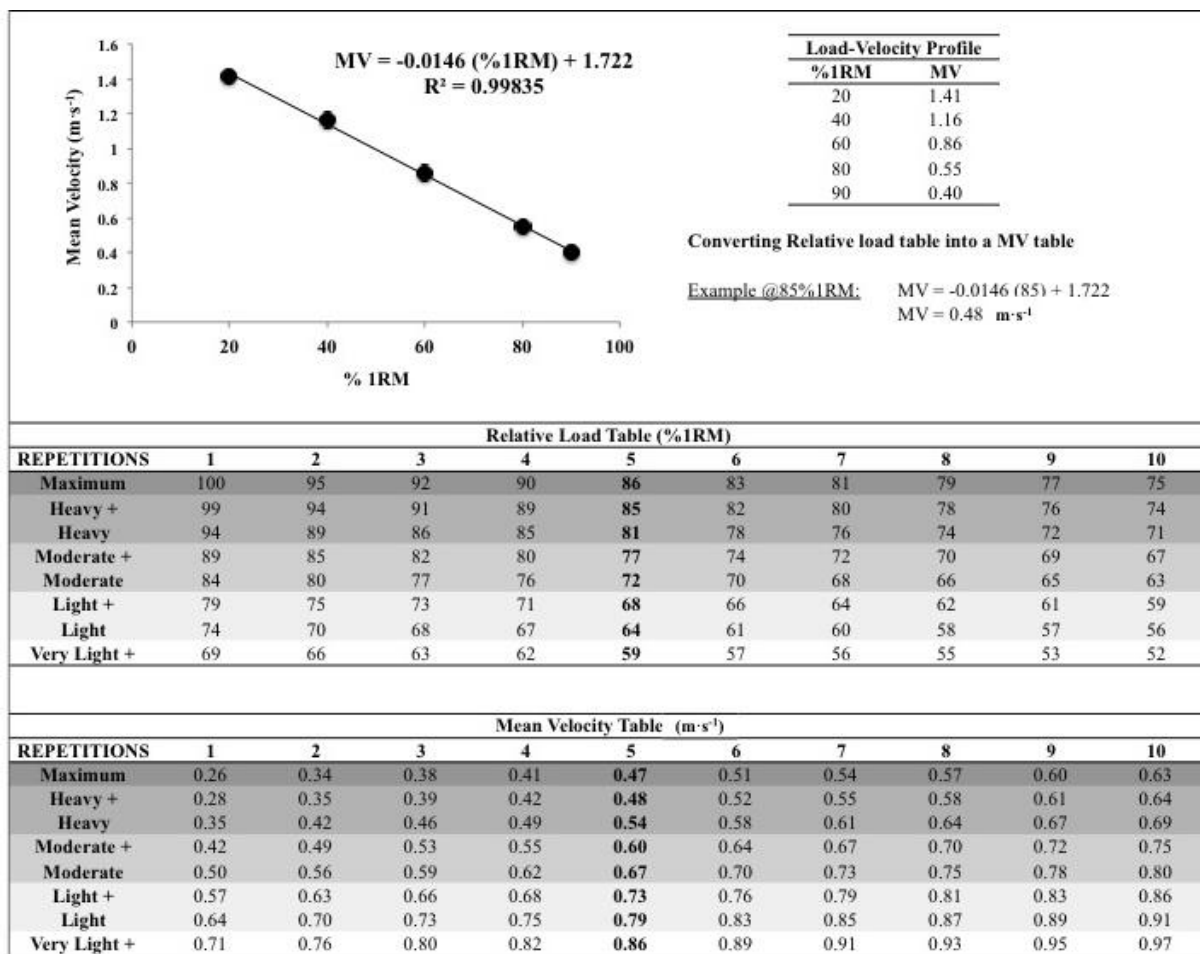


Figure 29. An example of converting a relative load table into a mean velocity table using a load-velocity profile obtained from a representative participant.

Load-Velocity Profile (LVP) Assessment

Previous research has found that MV in the free-weight back squat is reliable at 20% 1RM, 40% 1RM, 60% 1RM, 80% 1RM and 90% 1RM but not 100% 1RM [103]. Therefore, in the present

study, individualised LVPs were developed using MV from 20% to 90% 1RM (Figure 29). During week one, the relative loads (20% to 90% 1RM) lifted in LVP-1 were based off the pre-testing 1RM load. For the post-testing 1RM assessment in week eight, which was also used as LVP-2, the warm-up relative loads (20% 1RM to 90% 1RM) were also based off the pre-testing 1RM load (Figure 28). This was done to observe the changes in MV with the same absolute loads between LVP-1 and LVP-2. However, for the LVP-3 session, the relative loads lifted (20% to 90% 1RM) were based off the post-testing 1RM assessment (Figure 27). This was done to compare MV changes with the same relative load between LVP-1 and LVP-3. At the commencement of the LVP sessions, participants performed the same cycling, dynamic stretching and bodyweight squats warm-up protocols as the 1RM assessment. The warm-up was then followed by back squat sets using 20% (3-repetitions), 40% (3-repetitions), 60% (3-repetitions), 80% (1-repetition) and 90% 1RM (1-repetition). Two minutes of passive recovery was given between sets. For sets that included more than one repetition (i.e. 20%, 40%, and 60% 1RM), the repetition with the fastest MV was included for the LVP regression (Figure 29), which [103]. Figure 29 demonstrates how the individualised LVPs were constructed by plotting MV against relative load and then applying a line of best fit to the data (Microsoft Excel 2016, Microsoft, Redmond, Washington, USA). A linear regression equation was then calculated and used to convert a relative load table into a MV table (Figure 29). The individualised MV table was then used to determine daily training loads during VBT.

Power and Speed Testing Session

Loaded Countermovement Jump (CMJ)

At the commencement of this session, the participants performed the same cycling, dynamic stretching and bodyweight squat warm-up as previously described, which was then followed by three bodyweight CMJ repetitions that were performed with maximal concentric effort. Participants then performed three sets of one repetition of the CMJ with 30% of the pre-test back squat 1RM with a one-minute rest period allocated between sets. The CMJ technique required participants to stand upright with feet approximately shoulder width apart with hips and knees fully extended. The barbell was positioned across the superior aspect of the upper trapezius at all times. Participants were instructed to descend into a self-selected depth and immediately follow with a jump for maximum height. The CMJ repetition with the fastest PV and highest PP output (which was always the same repetition) was collected from the LT and used for further analysis.

20m Sprint

Following the CMJ assessment, participants then performed an additional warm-up protocol prior to the 20m sprints which consisted of repeated jogging efforts followed by two sets of 20m progressive running acceleration efforts. Timing lights (Swift Speedlight Timing Systems, Swift Performance, Brisbane, Australia) were used to measure each sprint with gates placed 1.5 m wide at the start line, 5 m, 10 m, and 20 m distances [112]. Two minutes of rest was allocated between trials, and participants commenced the 20 m sprints when they were ready in a crouched starting position with the lead foot on the start line. The fastest of the three trials, which also happened to contain the best 5m and 10m times, was used for further analysis.

505 Change of Direction Test (COD)

Participants assumed a crouched starting position and sprinted for 15 m before changing direction off a designated turning point and sprinting back towards the start line for another 5m [113]. Timing gates were positioned 5 m from the designated turning point. Participants completed the COD test six times; three with the dominant leg (DL) turning off the designated line and three with the non-dominant leg (NDL). Two minutes of rest was given between trials, and the quickest trial on each leg was used for further data analysis.

Training Protocols

At the commencement of each training session, participants performed the same cycling, dynamic stretching and bodyweight squat warm-up protocols as those mentioned prior to the 1RM assessment. Regardless of the training group, all participants then performed four loaded sets of warm-up squats using 20% (3-repetitions), 40% (3-repetitions), and 60% 1RM (3-repetitions), followed by one repetition at the assigned sessional training load. Following these squat sets, two minutes of rest was given prior to the commencement of the training sets. Crucially, all repetitions (warm-up and training repetitions) were performed with a controlled eccentric velocity but maximal concentric effort.

As seen in Figure 30A, the PBT group lifted with prescribed relative loads varying from 59% – 85% 1RM that were based on their pre-test 1RM. However, the VBT loads could be adjusted (higher or lower) from set-to-set in order to reach the prescribed sessional target velocity from the participant's individualised LVP and subsequent MV table (Figure 29). The target velocity

corresponded to the same relative load as the PBT session. For example, in session 1, the PBT group trained with 68% 1RM load (Figure 30A), whereas an example participant from the VBT group trained with adjustable loads to achieve a sessional average repetition velocity of $0.73 \text{ m}\cdot\text{s}^{-1}$, which corresponded to 68% 1RM in the MV table (Figure 29).

In order to determine the first set's training load for each VBT session, the MV of the last set of the warm-up (the 1-repetition performed at the assigned sessional training load) was compared with the target velocity in the MV table (Figure 29). If the MV was $0.06 \text{ m}\cdot\text{s}^{-1}$ higher or lower than the target velocity, the first set was adjusted by $\pm 5\%$ 1RM. If the difference was $0.12 \text{ m}\cdot\text{s}^{-1}$ higher or lower than the target velocity then a $\pm 10\%$ 1RM load adjustment was made, and so on. This was based on previous research that found the smallest detectable difference (normal variation in velocity) in MV between sessions for the full-depth free-weight back squat was $\pm 0.06 \text{ m}\cdot\text{s}^{-1}$ with relative loads ranging from 20% to 90% 1RM [103]. During the VBT sessions, once a set of five repetitions was completed, the load for the subsequent set could be adjusted by $\pm 5\%$ 1RM if the average of the MV for the five repetitions of the previous set was $0.06 \text{ m}\cdot\text{s}^{-1}$ higher or lower than the target velocity for that session.

In this manner, all participants from both training groups completed 25 repetitions per session, but the training load for the VBT group could be adjusted according to the average MV of the preceding set's repetitions. It should be noted that during the two-minute inter-set rest period, the principal researcher assessed the average set velocity (which was transmitted from the LT to an iPad via Bluetooth) and made appropriate load adjustments for each participant within the VBT group. Although this was not difficult, in the real world, this would add some additional complexity for an athlete compared to PBT.

The average repetition velocity deviation for each session was determined by calculating the average difference in the MV of each repetition compared to the MV from the individualised LVP (Figure 30A). The average repetition velocity was determined as the average MV for each participant in each session (Figure 30B). Average repetition load was calculated as the average relative load lifted for each repetition in a session (Figure 30C).

Rating of Perceived Exertion (RPE) Measures

Participants were asked to rate their perceived exertion 30 minutes following each session based on the CR-10 RPE scale [114]. When the participant was shown the scale they were asked the question "how was the session?" [115]. The participant would then verbally indicate a number from 0 to 10 on the scale after comparing with the corresponding descriptor. A rating of 0

corresponded with rest and was associated as the least difficult, whereas 10 referred to maximal and the most difficult.

Statistical Analyses

Changes within and between groups for pre- and post-testing measures of 1RM, LVP (MV at 20%, 40%, 60%, 80%, 90%, and 100% 1RM), CMJ, 20 m sprint times (5 m, 10 m, and 20 m), and COD times were analysed using a two-way repeated measures multivariate analysis of variance (MANOVA) with a type-I error rate set at $\alpha \leq 0.05$. A between groups MANOVA was also used to detect differences in the training session data including average repetition velocity loss, average repetition velocity, average repetition load, and session RPE. If a MANOVA showed significant differences between groups, a Holm's Sequential Bonferroni post hoc test was applied to determine significant differences. The MANOVA analysis was conducted using a statistical software package (SPSS version 22.0 IBM, Armonk, NY, USA). ES ($\pm 95\%$ confidence intervals) were calculated using Cohen's d and were interpreted as trivial (≤ 0.2), small (0.20 – 0.60), moderate (0.60 – 1.20), large (1.20 – 2.00) or very large (≥ 2.0) [116]. All data were analysed for practical significance using magnitude-based inferences [117]. The within group chances that the magnitude of change was greater than the smallest worthwhile change ([SWC] = 0.2 x within group standard deviation [SD]) from pre- to post-testing was interpreted according to the following scale: $<0.5\%$ *almost certainly not*, 0.5 – 5% *very unlikely*, 5 – 25% *unlikely*, 25 – 75% *possibly*, 75 – 95% *likely*, 95 – 99.5% *very likely*, $>99.5\%$ *almost certainly* [116]. In addition, the between group comparison for pre- and post-testing measures was assessed (SWC = 0.2 x between group SD). If the 90% CI crossed both the upper and lower boundaries of the SWC/Difference, the magnitude of change was described as *unclear* [116]. Data are reported as mean \pm SD unless stated otherwise.

RESULTS

Training Results

The training data including the average repetition load, the average repetition velocity, the average repetition velocity deviation per session, and sessional RPE scores are presented in Figure 30 for both groups.

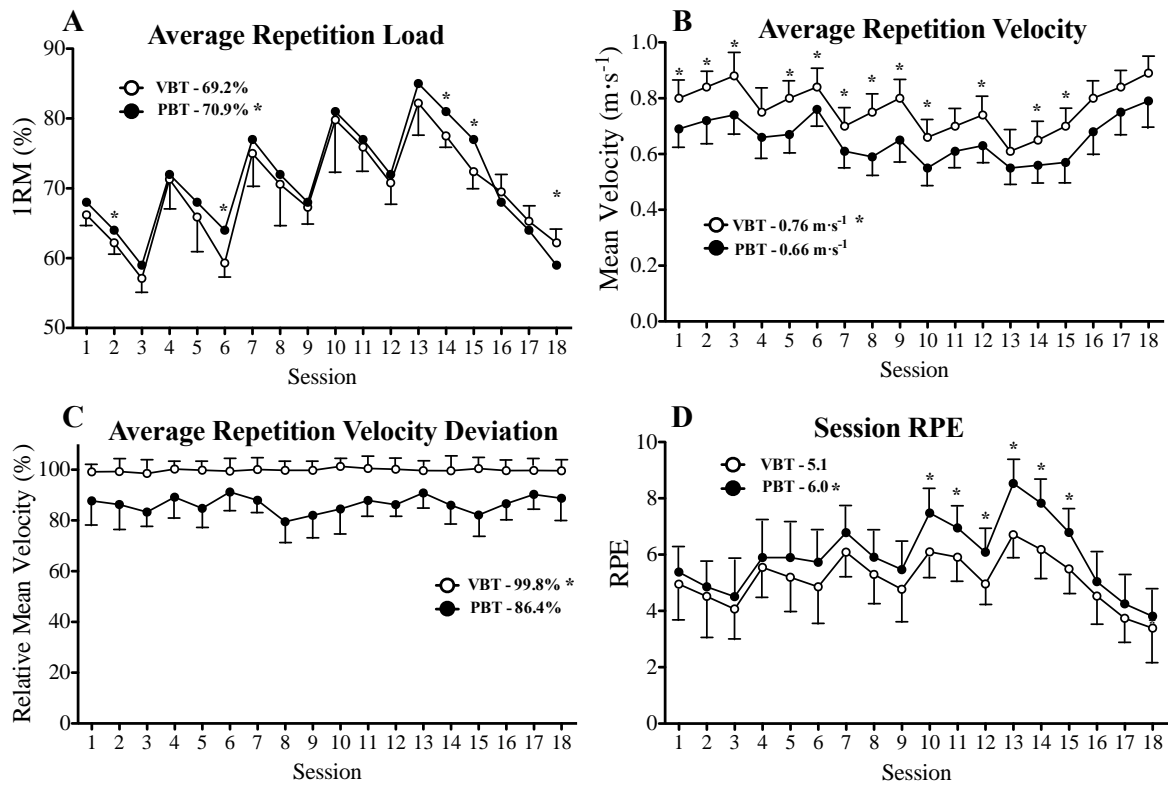


Figure 30. Sessional values for (A) average repetition load (%1RM), (B) average repetition velocity, (C) average repetition velocity deviation compared to the intended velocity from the individualised load-velocity profile, (D) session rating of perceived exertion [RPE]. * $p < 0.05$.

Every participant from both training groups completed 100% of all sessions. Over the entire training period, the average relative training load was significantly less for the VBT group compared to PBT ($p < 0.05$, $69.2 \pm 7.0\%$ 1RM vs. $70.9 \pm 7.4\%$ 1RM); specifically, significant differences were observed in sessions 2, 6, 14, 15, and 18 (Figure 30A). Participants from the VBT group trained with significantly faster MV compared to PBT ($0.76 \pm 0.08 \text{ m}\cdot\text{s}^{-1}$ vs. $0.66 \pm 0.08 \text{ m}\cdot\text{s}^{-1}$) and significant differences were observed in 12 of the 18 sessions (Figure 30B). The fastest repetition velocities in both training groups matched the expected velocities from the individualised LVP in every training session. Overall, the average magnitude of session velocity deviation matched the intended target velocity for the VBT group ($-1.2 \pm 3.5\%$) but there was a significantly greater magnitude of velocity loss for the PBT group ($-13.6 \pm 6.8\%$) compared to the intended velocity (Figure 30C). Session RPE scores were significantly higher across the six week period in the PBT group (6.0 ± 1.7) compared to VBT (5.1 ± 1.8) with significant differences reported during sessions 10, 11, 12, 13, 14, and 15 (Figure 30D). Figure 4 provides examples of the individualised training load approach for two representative participants in the VBT group with respect to pre-/post- increases in their 1RM compared to PBT group. VBT participant-1

typically lifted more than the PBT group with an average repetition load of 74.3% 1RM throughout the training study, and showed the greatest improvement in 1RM with a 14.3% increase (137.5 to 157.5kg). Comparatively, participant-2 from the VBT group typically lifted with lighter loads than PBT group (68.8% 1RM) but still had considerable gains in his 1RM with an 11.1% increase (157.5 to 175kg).

Testing Results

Following the training intervention, statistically significant and *almost certainly* beneficial improvements were made for VBT and PBT groups in 1RM strength (VBT: 11.3% vs. PBT: 12.5%), PV-CMJ (7.4% vs. 4.0%), PP-CMJ (7.7% vs. 6.0%), 5m sprint (-6.5% vs. -3.3%), 10m sprint (-3.8% vs. -2.0%), 20m sprint (-1.9% vs. -0.9%), and COD times (-5.4% vs. -3.6%) compared to pre-testing measurements (Table 6). Overall, there were no significant differences ($p > 0.05$) between VBT and PBT groups for any testing measures at pre- and post-testing time points (Table 7). However, there were *likely* favourable training effects for PBT group compared to VBT group in 1RM changes (ES = 0.62) whilst VBT group had *likely* or *possibly* favourable training effects for NDL-COD (ES = 0.41), 5m (ES = 0.56) and 10m sprint times (ES = 0.53), as well as MV@100% 1RM (ES = 0.50) (Figure 32). *Unclear* training effect differences (ES = 0.00 – 0.34) were seen for all other testing measures between groups (Figure 32). As seen in Figure 33, LVP-2 was significantly different to LVP-1 and LVP-3 for both groups across the relative load spectrum (20% 1RM – 90% 1RM).

Table 6. Within group comparisons for pre- and post-performance measures, differences, percent changes, and statistical analyses.

	VBT						PBT					
	Pre-	Post-	Absolute Δ	% Δ	p-value	ES	Pre-	Post-	Absolute Δ	% Δ	p-value	ES
1RM (kg)	136.7 \pm 20.9	153.6 \pm 21.4	17.0 \pm 4.8	11.3	2.25E ⁻⁸	0.80	135.2 \pm 11.0	152.1 \pm 12.8	19.1 \pm 4.3	12.5	2.74E ⁻⁹	1.41
PV - CMJ (m·s⁻¹)	2.50 \pm 0.23	2.69 \pm 0.25	0.19 \pm 0.03	7.4	5.27E ⁻¹⁰	0.79	2.53 \pm 0.19	2.63 \pm 0.21	0.10 \pm 0.02	4.0	3.79E ⁻¹⁰	0.50
PP - CMJ (W)	4527 \pm 913	4869 \pm 968	342 \pm 70	7.7	2.87E ⁻⁹	0.36	4517 \pm 617	4783 \pm 634	266 \pm 132	6.0	2.33E ⁻⁵	0.42
MV@20%1RM (m·s⁻¹)	1.29 \pm 0.12	1.37 \pm 0.13	0.08 \pm 0.02	6.5	2.71E ⁻⁸	0.64	1.25 \pm 0.11	1.33 \pm 0.12	0.08 \pm 0.03	6.3	3.00E ⁻⁸	0.69
MV@40%1RM (m·s⁻¹)	1.12 \pm 0.07	1.20 \pm 0.07	0.08 \pm 0.03	7.4	1.13E ⁻⁹	1.14	1.08 \pm 0.06	1.14 \pm 0.07	0.08 \pm 0.02	6.4	6.20E ⁻⁶	0.92
MV@60%1RM (m·s⁻¹)	0.90 \pm 0.06	0.97 \pm 0.08	0.07 \pm 0.02	7.9	1.84E ⁻⁷	0.99	0.87 \pm 0.06	0.93 \pm 0.07	0.06 \pm 0.02	6.9	6.84E ⁻⁸	0.92
MV@80%1RM (m·s⁻¹)	0.68 \pm 0.07	0.76 \pm 0.07	0.07 \pm 0.04	11.6	1.12E ⁻⁸	1.14	0.65 \pm 0.07	0.73 \pm 0.07	0.08 \pm 0.03	9.0	1.97E ⁻⁵	1.14
MV@90%1RM (m·s⁻¹)	0.50 \pm 0.06	0.58 \pm 0.06	0.08 \pm 0.06	18.3	3.88E ⁻⁹	1.33	0.48 \pm 0.07	0.55 \pm 0.07	0.06 \pm 0.03	13.8	8.99E ⁻⁴	1.00
MV@100%1RM (m·s⁻¹)	0.24 \pm 0.05	0.48 \pm 0.06	0.25 \pm 0.07	100.2	1.88E ⁻⁸	4.00	0.23 \pm 0.04	0.44 \pm 0.05	0.21 \pm 0.10	89.7	3.63E ⁻⁵	3.50
5m Sprint (s)	1.16 \pm 0.06	1.09 \pm 0.06	0.07 \pm 0.02	-6.5	7.77E ⁻⁷	1.17	1.14 \pm 0.06	1.10 \pm 0.07	0.04 \pm 0.01	-3.3	2.47E ⁻⁶	0.61
10m Sprint (s)	1.90 \pm 0.08	1.83 \pm 0.07	0.07 \pm 0.03	-3.8	2.35E ⁻⁶	0.93	1.90 \pm 0.10	1.86 \pm 0.10	0.04 \pm 0.01	-2.0	1.25E ⁻⁷	0.40
20m Sprint (s)	3.20 \pm 0.11	3.14 \pm 0.12	0.06 \pm 0.02	-1.8	7.64E ⁻⁷	0.52	3.21 \pm 0.16	3.18 \pm 0.16	0.03 \pm 0.01	-0.9	3.20E ⁻⁶	0.19
DL - COD (s)	2.32 \pm 0.10	2.20 \pm 0.10	-0.13 \pm 0.04	-4.9	8.28E ⁻⁷	1.20	2.30 \pm 0.10	2.21 \pm 0.11	-0.09 \pm 0.03	-3.6	6.93E ⁻⁶	0.86
NDL - COD (s)	2.38 \pm 0.12	2.24 \pm 0.10	-0.14 \pm 0.07	-5.4	2.19E ⁻⁵	1.27	2.34 \pm 0.10	2.25 \pm 0.11	-0.09 \pm 0.07	-3.5	1.53E ⁻³	0.86

DISCUSSION

The main hypotheses of this study were that VBT would result in greater adaptations for strength, power and speed assessments compared to PBT due to the individualised approach of VBT. Participants in both groups *almost certainly* improved their performance in all testing measures except in the 20m sprint assessment for the PBT group. There were favourable training effects for VBT in preference to PBT for MV@100%1RM (*possibly*), 5m sprint (*likely*) and 10m sprint times (*possibly*), as well as NDL-COD (*possibly*). However, PBT group had *likely* favourable increases in 1RM compared to VBT group. Notably, the strategy of adjusting load to achieve a target velocity made the VBT sessions significantly easier than PBT (RPE = 5.1 vs. 6.0) and allowed the VBT group to perform training repetitions with significantly faster velocities (MV = 0.76 m·s⁻¹ vs. 0.66 m·s⁻¹). This may explain the slightly favourable VBT effects for the sprint (5m and 10m) and NDL-COD assessments compared to PBT. Contrastingly, the significantly greater training load (~1.7% 1RM greater load per repetition) lifted by the PBT group could explain the non-significant but *likely* favourable 1RM strength improvements compared to VBT.

Table 7. Between groups comparison of testing measures at pre- and post-six weeks of squat training.

	VBT vs. PBT (Pre-)			VBT vs. PBT (Post-)		
	p-value	ES	MBI	p-value	ES	MBI
1RM (kg)	0.858	0.07	Unclear	0.977	0.07	Unclear
PV – CMJ (m·s ⁻¹)	0.737	-0.14	Unclear	0.572	0.25	Unclear
PP – CMJ (W)	0.977	0.01	Unclear	0.798	0.10	Unclear
MV@20%1RM (m·s ⁻¹)	0.481	0.34	Unclear	0.439	0.31	Unclear
MV@40%1RM (m·s ⁻¹)	0.210	0.59	Unclear	0.279	0.41	Unclear
MV@60%1RM (m·s ⁻¹)	0.272	0.48	Unclear	0.494	0.26	Unclear
MV@80%1RM (m·s ⁻¹)	0.310	0.44	Unclear	0.625	0.14	Unclear
MV@90%1RM (m·s ⁻¹)	0.276	0.34	Unclear	0.571	0.17	Unclear
MV@100%1RM (m·s ⁻¹)	0.451	0.16	Unclear	0.195	0.48	Unclear
5m Sprint (s)	0.330	0.32	Unclear	0.621	-0.15	Unclear
10m Sprint (s)	0.929	0.00	Unclear	0.314	-0.34	Unclear
20m Sprint (s)	0.839	-0.07	Unclear	0.512	-0.27	Unclear
DL – COD (s)	0.723	0.14	Unclear	0.784	-0.06	Unclear
NDL – COD (s)	0.383	0.31	Unclear	0.893	-0.08	Unclear

This is the first study to analyse the effect of using an individualised LVP to modify training load to achieve a prescribed target velocity. Interestingly, even though there were only small (ES = 0.23) differences in relative load lifted between groups (Figure 30A), the subtle decreases in

load for the VBT group (in order to achieve the intended sessional target velocity) resulted in large (ES = 1.25) differences in the MV of the training repetitions between groups (Figure 30B). As a consequence, the significantly faster squat velocities reported by the VBT group during training may have assisted with the slightly favourable improvements in 5m sprint (~3%), 10m sprint (~2%) sprint and NDL-COD times (~2%) compared to PBT. These results are in accordance with previous research showing the development of maximal strength in the squat exercise can translate to improvements in sprint performance, particularly for short/medium sprints (<30m) [5, 118]. Furthermore, improved squatting strength has also been shown to improve other markers of performance such as jumping and change of direction [56, 119].

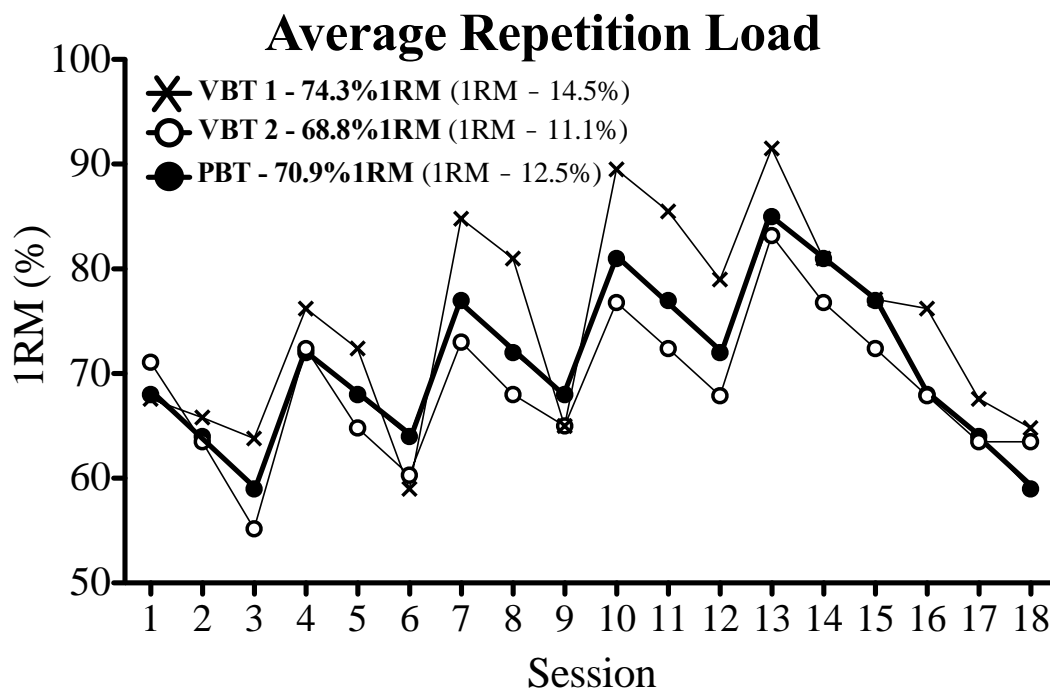


Figure 31. Average repetition load for each session obtained from two individuals in the VBT group compared to the PBT group. Average training load (%1RM) and the magnitude of 1RM increase are provided for the two VBT individuals and the PBT group

An important finding in the present study was that while both groups significantly improved their strength, they also enhanced their velocities against all of the same absolute loads in the LVP from LVP-1 to LVP-2, which was to be expected according to the load-velocity relationship [31]. As seen in Table 2, the absolute change in the velocities across the relative load spectrum was very similar between groups (LVP-1 vs. LVP-2) even though the VBT group trained with significantly faster training repetition velocities compared to PBT. This suggests the intent to move the bar as

rapidly as possible is an important stimulus for enhancing velocity against a given load, regardless of training method. Furthermore, there were no significant differences in MV between LVP-1 and LVP-3 across the relative load spectrum (20% 1RM – 90% 1RM) despite the increases in maximal strength for both groups (Figure 33). Similar findings were also reported by González-Badillo and Sánchez-Medina [31] who found there were no significant change in velocities (ICC = 0.81 – 0.91; CV = 0.0 – 3.6%) across the relative load spectrum (30% to 100% 1RM) from a bench press LVP performed before and after six weeks of upper body strength training, despite an increase in maximal strength of 9.3%. Thus, the present study further indicates that LVPs remain stable even when maximal strength changes.

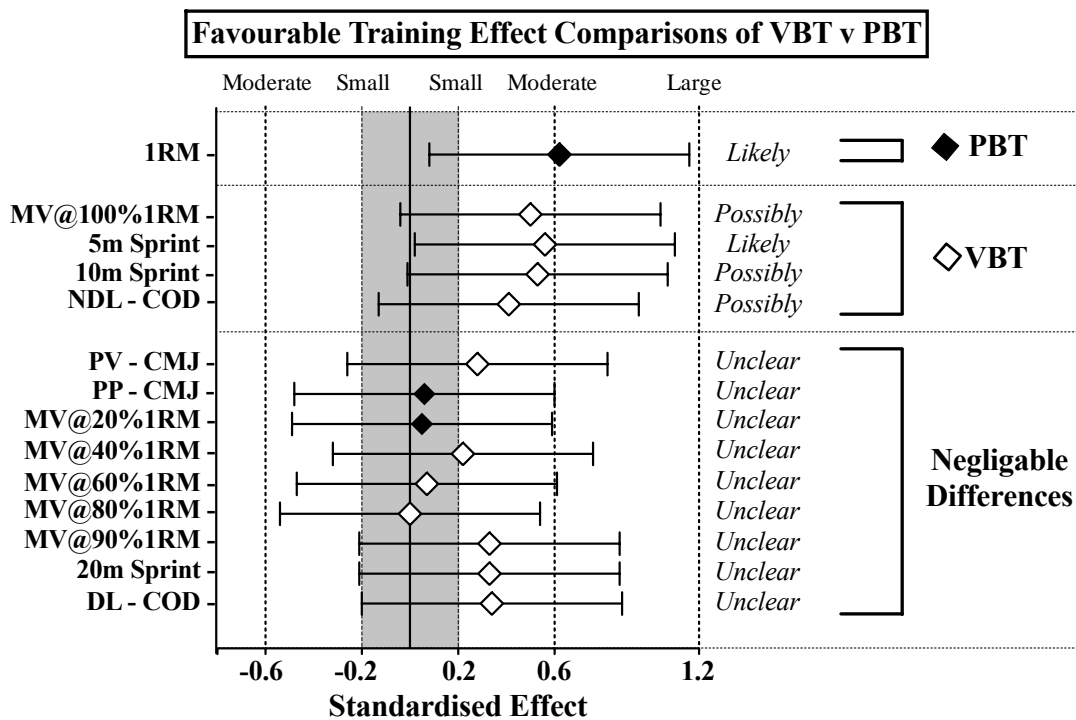


Figure 32. Between group effect size comparisons for the changes in testing measures.

Compared to PBT, it was found that participants in the VBT group also perceived training to be easier (Figure 30D); this was particularly pertinent during resistance training sessions 10 to 15 (pertaining to loads of 72% to 85% 1RM). During these sessions the VBT group perceived these sessions easier when compared to the PBT group, despite there being no significant differences in the relative training intensity of sessions 10 (81% 1RM), 11 (77% 1RM), 12 (72% 1RM), and 13 (85% 1RM). Although it is unclear why these sessions were perceived easier, reductions in perception of effort while completing similar external loading may be beneficial for reducing subjective measures of training load [120].

As previously mentioned, VBT group lifted with faster average repetition velocities but lower average repetition loads compared to PBT group (Figure 30). Notably, both groups significantly improved their 1RM after the six weeks of squat training (VBT: ES = 0.80 vs. PBT: ES = 1.41) (Table 6). However, even though there were no significant differences between groups, PBT group had *likely* favourable increases in 1RM compared to VBT group (Figure 32). This suggests that heavier loads and the intent to move an external load as fast as possible while producing force rapidly are critical factors for enhancing strength, and potentially more important than the velocity output itself, so long as concentric muscular failure is not achieved. Previous VBT research by Padulo et al. [13] showed that strength-trained males (1RM/body mass = ~1.3) increased their 1RM by 10.2% after performing maximal concentric velocity bench press training for 3-weeks (6-sessions), where training sets were ceased once the repetition velocity dropped below 20% of the fastest repetition from the first set. By comparison, another group (1RM/body mass = ~1.3) had no significant change in 1RM (0.17% increase) after training with the same exercise and training frequency but performed repetitions with self-selected concentric velocity and to concentric muscular failure. The greater increases in 1RM observed for the VBT group in the Padulo et al. [13] study was attributed to a greater recruitment of motor units at a high firing frequency which can improve the RFD. Consequently, it could be speculated that the requirement for all participants to use maximal intent during the concentric phase increased muscle activation and firing frequency of the lower body muscles. This may have contributed to improvements in the RFD that led to the increases in 1RM for both VBT and PBT groups [121].

A limitation of this study was that hypertrophic measures such as muscle cross sectional area and girth measurements using ultrasound, or constant tension tape were not assessed. Based off previous findings, it is possible that since the PBT group performed the same training volume (sets and repetitions) but higher relative loads, the PBT group may have experienced greater gains in muscle hypertrophy in the lower body musculature, but this suggestion is purely speculative. Since training load and volume are critical to optimising strength and power adaptations, future studies could look to explore the combination of multiple VBT methods. For example, studies have explored the use of velocity loss thresholds to terminate repetitions in a set to control training volume [20, 26]. Therefore, a combination of the LVP-VBT method to objectively prescribe relative training load prescription based on the physiological condition of an individual on a given day, and the implementation of velocity loss thresholds to account for the appropriate volume of repetitions could be of great use for individuals looking to train with accurate training load and volume.

	VBT			PBT		
	LVP-1	LVP-2	LVP-3	LVP-1	LVP-2	LVP-3
20% Δ 1RM($m\cdot s^{-1}$)	1.29 \pm 0.12	*1.37 \pm 0.13	1.30 \pm 0.13	1.25 \pm 0.11	*1.33 \pm 0.12	1.26 \pm 0.12
40% Δ 1RM($m\cdot s^{-1}$)	1.12 \pm 0.07	*1.20 \pm 0.07	1.11 \pm 0.08	1.08 \pm 0.06	*1.14 \pm 0.07	1.06 \pm 0.08
60% Δ 1RM($m\cdot s^{-1}$)	0.90 \pm 0.06	*0.97 \pm 0.08	0.89 \pm 0.08	0.87 \pm 0.06	*0.93 \pm 0.07	0.88 \pm 0.07
80% Δ 1RM($m\cdot s^{-1}$)	0.68 \pm 0.07	*0.76 \pm 0.07	0.67 \pm 0.06	0.65 \pm 0.07	*0.73 \pm 0.07	0.65 \pm 0.07
90% Δ 1RM($m\cdot s^{-1}$)	0.50 \pm 0.06	*0.58 \pm 0.06	0.49 \pm 0.05	0.48 \pm 0.07	*0.55 \pm 0.07	0.46 \pm 0.07
#100%1RM ($m\cdot s^{-1}$)	#0.24 \pm 0.05	#*0.48 \pm 0.06	#0.25 \pm 0.05	#0.23 \pm 0.04	#*0.44 \pm 0.05	#0.22 \pm 0.05

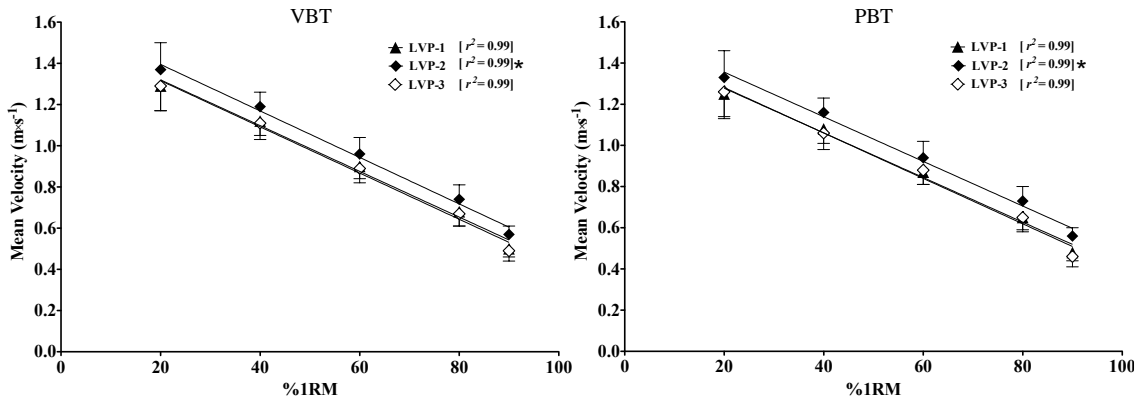


Figure 33. Load-velocity profiles (using mean velocity) at baseline (LVP-1), post-training 1RM assessment (LVP-2) and post-training load-velocity profile assessment (LVP-3). * denotes that LVP-2 velocities are significantly different to LVP-1 and LVP-2. # indicates that MV at 100%1RM was not included in the LVPs since it is not reliable

During the present study, participants were in a relatively controlled training environment where they refrained from performing other modes of training. Consequently, even though significant differences in load were reported between groups throughout the training study, this difference only resulted in a small ES (Figure 30A). However, in a team sport environment when multiple factors must be considered (technical skills, matches, conditioning etc.), other fatiguing elements could exacerbate the magnitude of velocity loss beyond that reported in the present study. This may be of additional benefit when using the LVP-VBT approach and assist in the mitigation of physical and psychological stressors that can negatively influence performance. Alternatively, training load can be increased to accommodate for participants who perform repetitions with faster velocities compared to their baseline LVP. For example, a participant in the VBT group lifted with heavier loads than PBT group for 13 of 18 training sessions (Figure 31). For this participant, the slightly higher training loads over the entirety of the training program compared to PBT group (74.3% 1RM vs. 70.9% 1RM) also led to slightly higher increases in 1RM compared to PBT (14.5% vs. 12.5%). Thus, a critical aspect to the LVP-VBT method is that it allows individuals to lift with appropriate loads on any given day to accommodate for individual rates of training adaptation.

In conclusion, both VBT and PBT methods were effective for improving strength, power output and sprint assessments. However, PBT may be slightly favourable for increasing maximal strength whilst VBT provided a slight advantage for enhancing sprint performance tasks. Even though most individuals displayed similar improvements in the testing measures regardless of training group, the VBT sessions were perceived less difficult and had greater repetition velocities. Therefore the LVP-VBT method may be beneficial for the management of perceived training loads, particularly in individuals who take part in numerous forms of training (e.g. resistance training, conditioning, technical/tactical). Furthermore, some individuals could benefit from the individualised approach of the LVP-VBT method used in the present study if maximal strength is likely to increase rapidly; such as when an individual returns to regular training following sedentary training periods (i.e. return from injury). That being said, if all repetitions are performed with maximal intent but not to concentric muscular failure, a periodised PBT resistance training program with regular training frequency and progressive overload can provide adequate stimulus for the enhancement of strength, power and sports performance tasks.

CHAPTER 8

GENERAL SUMMARY AND CONCLUSIONS

GENERAL SUMMARY

The central aim of this thesis was to investigate the efficacy of VBT and whether its use as a method of training is more favourable for enhancing strength, power and sprint times compared to more traditional PBT methods in strength-trained men. To achieve this, five studies were conducted in this thesis project to be able to examine the acute and chronic effects of VBT. In these five studies, the validity of two popular velocity measuring devices were examined (Study 1); the reliability and validity of the load-velocity relationship to predict 1RM was determined (Study 2); the reliability of PV, MPV and MV was investigated for the development of LVPs (Study 3); the kinetic and kinematic data was compared between three different VBT sessions and a PBT session (Study 4); and changes in maximal strength, power and sprint times after 6-weeks of VBT (LVP approach) versus PBT were investigated. Therefore, the studies in this thesis were designed to first, address the lack of research exploring velocity measuring devices and ultimately, the different VBT methods. Specifically, this research has shown that VBT is a valid alternative to more traditional PBT methods. Furthermore, VBT may provide coaches greater flexibility to regulate resistance-training sessions according to an athlete's sessional velocity measures and their individual differences in the rate of training adaptation.

In Study 1 (Chapter 3), the validity and reliability of multiple velocity-measuring devices was determined and one LT (GYM) stood out as being highly accurate for measuring PV and MV at 20%, 40%, 60%, 80%, 90% and 100% 1RM. In addition, the LT was also highly accurate for estimating MF and PF across the aforementioned six relative loads (20%-100% 1RM). However, some caution should be taken when using LT's for the assessment of MP and PP since it over predicted the power values at lighter loads, more specifically, 20% 1RM for MP and at 20% and 40% 1RM for PP. Contrastingly, the inertial sensor (PUSH) was only able to accurately estimate PF across all six relative intensities. Moreover, the accuracy of the inertial sensor to estimate MV, PV, MF, MP, and PP across all relative loads was questionable. These results contradicted previous studies that had found that the same inertial sensor was highly accurate for assessing PV and MV in the Smith machine back squat and dumbbell bicep curl and shoulder press exercises. It is likely that the different results were due to first, the fact that some statistical analyses methods were not reported, such as the CV, which is often reported in many validity papers; and second,

the differences in exercises, where the PUSH appears to be better suited to vertical movements on a Smith machine. In addition, Study 1 was the first research study to assess the validity of an inertial sensor across the entire relative intensity spectrum, which is important to discern for athletes who train at a variety of relative loads. Therefore, as resistance training is commonly performed with free-weights across the entire relative load spectrum, the LT was selected to measure velocity for the remainder of the studies contained within this thesis.

One rationale for VBT is for individualizing training loads based on daily changes in maximum strength without the need to perform 1RM assessments every session. Study 2 (Chapter 4) was the first study, to the author's knowledge, to show that the $1RM_{V1RM}$ prediction method using the load-velocity relationship was not reliable and valid enough to accurately predict maximal strength in the free-weight back squat. These findings did not support our hypothesis but since this study was published in 2016, two other studies have also reported similar findings in the free-weight deadlift and also the free-weight back squat. In accordance with our results, these two other studies also found that the V1RM used in the load-velocity relationship regression equation to predict 1RM was unreliable between sessions. As a result, the findings from Study 2 suggest that if the V1RM is applied in the linear regression equation to predict 1RM, the load-velocity relationship cannot accurately predict daily or training session specific 1RM for the free-weight back squat exercise. Therefore, this $1RM_{V1RM}$ prediction method was not used as a VBT method for the remainder of this thesis.

Study 3 (Chapter 5) was designed to determine whether three different concentric velocities were reliable and could be used to develop individualised LVPs, which was completed using the warm-up repetitions for the 1RM assessments. The results of this study showed that PV was highly reliable at all six relative intensities tested (20%, 40%, 60%, 80%, 90%, and 100% 1RM). Similarly, MPV and MV were highly reliable at all relative loads except 100% 1RM. Therefore, a coach should not incorporate the movement velocity at 100% 1RM if the LVPs are created from MPV or MV. These results suggest that PV, MPV and MV are all acceptable to develop LVPs and the individualised LVP could be used as a method for adjusting sessional training loads according to an individual's velocity measures, which are indicative of their readiness to train on a given day. Lastly, when the relative loads with reliable velocities were used to create LVPs, there was no difference between the correlations of LVPs using linear regression or second-order polynomial fits. Therefore, linear regression equations were developed for the LVPs in the remaining studies of this thesis since they are easier to calculate and implement in training.

Study 4 (Chapter 6) was devised so that the kinetic and kinematic data could be compared

between three different VBT sessions and a typical strength-oriented PBT session. The major findings from this study were that participants could sustain significantly faster MV and PV for repetitions performed during the LVP (MV: ES = 1.05; PV: ES = 1.12) and FS_{VL20} (MV: ES = 0.81; PV: ES = 0.98) sessions compared to the PBT session. In addition, the same two VBT methods allowed participants to perform repetitions with significantly less mechanical stress (CTUT, TUT, sCTUT, sTUT) while still completing similar amounts of work (MW, TW) compared to the PBT session. These findings for the LVP session were due to the subtle training load reduction (~5% 1RM) that was not statistically different to the PBT session. Contrastingly, the reason for the maintenance of higher sessional velocities and less TUT during the FS_{VL20} session was due to the completion of fewer repetitions (23.6 ± 2.0 vs. 25; ES = 1.01) compared to all other methods. Interestingly, no significant differences were observed for measurements of force (MF, PF), power (MP, PP) or training load lifted (ML, TL) between any of the experimental sessions. Consequently, the LVP and FS_{VL20} methods appear to be more objective, individualised training approaches than PBT for athletes performing strength-oriented training sessions due to greater maintenance of higher sessional movement velocities, less mechanical stress but still enduring similar measures of force, power, work and training load. Alternatively, the VS_{VL20} method could benefit individuals with time constraints since participants produced similar kinetic and kinematic data during this session compared to PBT and the other VBT methods but still completed the same total number of repetitions in a shorter period of time.

Finally, Study 5 (Chapter 7) was designed to determine the effectiveness of VBT compared to PBT over a six week training phase. Of the VBT methods assessed in Study 4 (Chapter 6), the LVP approach was chosen in preference to the FS_{VL20} method since this particular VBT method allowed for adjustments in resistance training load to accommodate for individual rates of training adaptation, and would also permit the same training volume (repetitions and sets) as PBT. The main hypotheses of this study were that VBT would result in greater adaptations for strength, power and speed assessments compared to PBT due to the individualised approach of VBT. The results of this study showed that participants in both groups *almost certainly* improved their performance in all testing assessments (1RM, CMJ, 20m sprint, and COD) except the PBT group in the 20m-sprint (ES = 0.19). Favourable training effects were observed for VBT group in preference to the PBT group in V_{1RM} (*possibly*), 5m sprint (*likely*) and 10m sprint times (*possibly*), as well as NDL-COD (*possibly*). However, the PBT group had *likely* favourable increases in 1RM compared to VBT group (12.5% vs. 11.3%). The likely favourable VBT effects in the sprint (5m and 10m) and NDL-COD assessments could be attributed to the significantly faster training

repetition velocities ($MV = 0.76 \text{ m}\cdot\text{s}^{-1}$ vs. $0.66 \text{ m}\cdot\text{s}^{-1}$). Contrastingly, the slightly favourable 1RM strength improvements for the PBT group compared to VBT group was likely due to the significantly greater training load ($\sim 1.7\%$ 1RM greater load per repetition) lifted, which also resulted in the PBT group perceiving their training sessions with greater difficulty (RPE = 6.0 vs. 5.1) than the participants in the VBT group. Therefore, VBT may provide a slight advantage over PBT since it provided comparable improvements in strength and power but was perceived as less difficult and permitted lower mechanical loading which could improve the management of resistance training loads, particularly with athletes who partake in numerous training modalities where fluctuations in strength and velocity may be exacerbated.

Collectively, these studies have shown that VBT methods are valid alternatives to more traditional PBT methods. Our main aim that VBT methods were more favourable for enhancing strength, power and sprint times was only partially supported. However, VBT methods were perceived with less difficulty but induced similar improvements in testing measures whilst avoiding additional mechanical loading, which could be beneficial for the management of athletes who partake in many fatiguing training modalities. Ultimately, the body of research presented provides practical and objective VBT methods to regulate resistance-training sessions and account for day-to-day fluctuations in an individual's performance. However, this thesis has also shown that if all repetitions are performed with maximal intended velocity but not to concentric muscular failure, a well planned, periodized resistance training program with regular training frequency and progressive overload that accounts for bouts of recovery (i.e. PBT) will also provide a similarly effective training stimulus to significantly enhance strength and power without the need of purchasing velocity measuring equipment.

LIMITATIONS

Although efforts were made to make the studies in this thesis as practical and ecologically valid as possible, some limitations are present. For example, in Study 1 (Chapter 3) the inertial sensor (PUSH) and LT (GYM) were validated against four LTs in a laboratory setup. Some researchers suggest 3D motion capture systems are the most accurate velocity assessment devices. However, advanced 3D motion capture systems must be synchronised with high-speed cameras and other technology. Furthermore, they require advanced computational skills and entail a significant cost. Moreover, the four LTs employed for the laboratory methods as the criterion measurement tool allowed for the quantification of both vertical and horizontal movements on

both sides of the barbell permitted a more centralised displacement position. Therefore, although some proponents of 3D motion analysis may claim that it is more accurate than an LT, the 4 LT in the laboratory system directly measured velocity (distance and time) essentially in 3D.

A limitation of Study 2 was that the findings regarding the $1RM_{V_{IRM}}$ prediction method (calculated by entering the V_{IRM} into a linear regression equation) are limited to the free-weight back squat exercise performed to full depth. Moreover, it does not mean that all approaches using the load–velocity relationship would fail. For example, the accuracy of 1RM predictions could be improved by using other variables (such as PV or MPV), alternative nonlinear regression models or other exercises. However, recent studies have investigated the accuracy of 1RM predictions using multiple methods in other free-weight exercises and have found the predictions of maximal strength to be questionable, which is in accordance with the results from this thesis project.

Within Study 3, one major limitation was that if an individual intended to train at relative loads greater than 90% 1RM, an LVP developed using MPV or MV may not be reliable. Therefore, LVPs utilizing MPV and MV could be problematic for individuals training at near-maximal relative loads in the free-weight back squat. However, when training at near maximal loads the training volume would likely be between 1–3 repetitions per set prior to concentric muscular failure occurring, and would not likely require VBT methods.

In Study 4, there were some potential limitations with the VBT methods. For example, time is required to setup the devices and modify the training load or repetition volume based on the velocity outputs. In addition, VBT methods require specialised velocity-measuring equipment, which can be cost prohibitive for some individuals. Nevertheless, velocity-monitoring devices are becoming more affordable and modern technology provides immediate feedback making it fairly simple to use VBT with large training groups. Furthermore, the strength and conditioning staff can set up the VBT equipment prior to training so that there is no increase in an athlete’s training time.

The studies in this thesis were designed specifically to focus on an exercise that improves athletic performance and is commonly performed amongst athlete groups, namely the free-weight back squat. However, athletes in most sporting codes will perform multiple exercises of the upper and lower body to improve athletic performance and reduce the risk of injury. Therefore, the investigation of a single exercise is a limitation of this research, but by investigating a single exercise, more time and effort could be spent on answering specific research questions so that other coaches and researchers can then apply these results to other exercises.

DIRECTIONS FOR FURTHER RESEARCH

Several directions for further research have been described within each separate study throughout this thesis. In summary, future research examining 1RM prediction methods could utilise different machine and free-weight exercises. Future training studies could assess the efficacy of VBT methods using multiple exercises (upper and lower body). As mentioned previously, one of the great benefits of VBT (LVP approach) is that an athlete can train with appropriate resistance training loads that account for their individual rates of progression. This could be hugely beneficial for athletes recovering from injury given the differences in the severity of injuries and the rate of recovery. Alternatively, the same VBT method could be employed for individual's who have been sedentary or not trained for a period of time and respond differently to the early stages of training. Additionally, providing participants are technically proficient with resistance training exercises, VBT methods could be conducted with different populations, including women, older adults, adolescent individuals, or anyone who is likely to increase strength rapidly. Lastly, future training studies could look to incorporate multiple VBT methods. For example, an LVP could be used to determine the resistance-training load from the monitored velocity outputs of the warm-up repetitions. Following this, velocity loss thresholds could then be implemented to control for the resistance training volume according to the training goal of a particular session.

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APPENDIX A: UNIVERSITY ETHICS COMMITTEE APPROVAL LETTER

Project 12191 BANYARD Ethics Approval

Research Ethics

Sent: Monday, 15 December 2014 3:10 PM
To: Harry BANYARD; mcgee00@hotmail.com
Cc: Greg HAFF; Ken NOSAKA; Research Assessments; FHES Student Information Office
Attachments:  [Conditions of approval.pdf \(50 KB\)](#) [Open as Web Page]

Dear Henry

Project Number: 12191 BANYARD

Project Name: The effects of velocity-based training on fatigue, strength and power

Student Number: 6042260

The ECU Human Research Ethics Committee (HREC) has reviewed your application and has granted ethics approval for your research project. In granting approval, the HREC has determined that the research project meets the requirements of the *National Statement on Ethical Conduct in Human Research*.

The approval period is from 15 December 2014 to 28 February 2017.

The Research Assessments Team has been informed and they will issue formal notification of approval. Please note that the submission and approval of your research proposal is a separate process to obtaining ethics approval and that no recruitment of participants and/or data collection can commence until formal notification of both ethics approval and approval of your research proposal has been received.

All research projects are approved subject to general conditions of approval. Please see the attached document for details of these conditions, which include monitoring requirements, changes to the project and extension of ethics approval.

Please feel free to contact me if you require any further information.

Kind regards

Rowe

Rowe Oakes

Ethics Support Officer, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive,
Joondalup, WA 6027

Tel: +61 08 6304 2943 | Fax: +61 08 6304 5044 | CRICOS IPC 00279B

APPENDIX B: INFORMATION LETTER – CHAPTER 3, 4, AND 5: STUDY 1, 2, 3

Readers should be aware that during the original proposal, studies 1, 2 and 3 were initially planned as one study, which was known as Study 1. However, since collecting and analysing the data we realized there were more questions that needed to be answered.



Information Letter to Participants

Title of the Project: Validity and Reliability of the Load-Velocity relationship to predict Back Squat 1RM

Study 1

Investigator: Harry Banyard (PhD Candidate)

Supervisors: Dr. Greg Haff and Professor Ken Nosaka

School of Exercise and Health Sciences
Edith Cowan University
270 Joondalup Drive, Joondalup WA 6027

Thank you for expressing an interest in the study. The purpose of this information letter is to provide you with an overview of the study in which you may participate in as a subject.

Purpose of the study

The purpose of this study is to establish (1) the validity of the load-velocity relationship to estimate the back squat 1-repetition maximum (1RM); (2) recommendations to follow for a reliable back squat 1RM estimation; (3) day-to-day variation of the actual 1RM; (4) if the day-to-day variation in the actual 1RM can be detected in the estimated 1RM.

Background

Velocity-based strength training requires an individual to perform an exercise with maximal speed/velocity on the concentric movement, which can be accurately monitored using a device called a position transducer. However, the commencement of velocity-based strength training requires an individual's 1RM and the velocity that is associated with the 1RM for a given exercise. One rationale for using velocity as a predictor of maximal strength is related to the overall time commitment associated with performing traditional 1RM assessments with large squads of team sport athletes. Moreover, a 1RM assessment performed within a season maybe problematic, as it would require an athlete to sacrifice a strength training session and perform lifts at 100% intensity

when they may not be fully recovered from competition. Additionally, even though 1RM testing is considered extremely safe, an increased risk of injury can occur if 1RM tests are performed incorrectly or by novice athletes who lack the technical skills required to perform the test. Therefore, a simpler, faster method to determine an individual's maximal strength has been suggested in the scientific literature. For the bench press exercise, the load-velocity relationship has been used to reliably predict the 1RM in recreationally trained individuals. However, to the best of our knowledge no studies have used the load-velocity relationship to predict the 1RM for the back squat exercise.

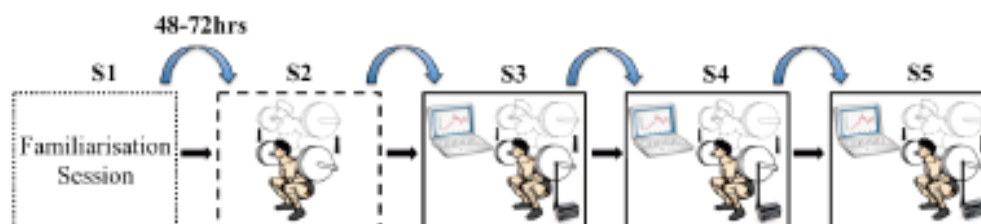
Methods

Participants

As a volunteer, you must have at least 6 months of strength-training experience, be able to back squat 150% of your body weight, and must be without any current musculoskeletal injuries. Data collected from you in this study will be kept in a secure cabinet on the university premises with only the chief investigator having access to the data. Prior to the onset of this study you must complete an informed consent form, medical questionnaire and pre-exercise checklist.

Procedure

As a participant in this study you are required to attend 5 testing sessions (S1 – S5; 48 - 72 hours apart) for the duration of approximately 45 mins/session at Edith Cowan University, Joondalup Campus, commencing in the strength lab, building 19, room 19.149. The first session (S1) will be used to familiarise you with the testing procedures, recording of height, weight, and completion of all required documentation. Session 2 (S2) will require you to perform a 1RM back squat test so that accurate warm up loads (%1RM) can be used for sessions 3 to 5 (S3, S4, and S5) which will also be 1RM back squat tests.



IRM Back Squat

At the beginning of sessions 2 to 5 (S2, S3, S4, and S5) you will perform a warm-up procedure consisting of 3 minutes pedalling at 100W on a cycle ergometer followed by a squat protocol comprising 3 repetitions at 20% 1RM; 3 repetitions at 40% 1RM, 3 repetitions at 60% 1RM; 1 repetition at 80% 1RM; and 1 repetition at 90% 1 RM (these loads will be based on your estimated 1RM for S2). On completion of the warm-up the 1RM back squat assessment will be performed. For every squat repetition attempted you will be instructed to perform the downward (eccentric) phase at a consistent, self-selected speed but to perform the upward (concentric) phase as fast and explosive as possible. Regarding rest periods, two minutes passive recovery will be given between warm-up sets and three minutes between 1RM back squat attempts. The Edith Cowan University Human Research Ethics Committee has approved this study.

Potential Risks

1RM testing is considered extremely safe, however, an increased risk of injury can occur if 1RM tests are performed incorrectly or by novice athletes who lack the technical skills required to perform the test. To minimise potential risks all participants will be screened for contraindications to exercise and must demonstrate proficiency with the back squat exercise. Researchers with extensive experience will monitor all testing sessions. Other precautions include a familiarisation session to instruct participants on correct technique and testing methods; the use of safety racks; and the addition of two spotters standing either side of the barbell ready to assist should a failed lift occur.

Potential Benefits

The 1RM test is considered a valuable performance assessment often conducted on a per fee basis when consulting athletes. In addition, each testing session you will receive free personal training on correct squatting technique. Moreover, by taking part in this study you will be able to prescribe accurate loads for the back squat exercise from your 1RM test. In addition, you will have the chance to learn how the 1RM can be estimated from the warm-up lifts and observe how current research techniques are performed while gaining an insight into the test involved. A summary of results for this study will be provided to you on request.

Privacy and Confidentiality

All information collected during this research will remain confidential and will not be used for any

other purpose other than this study. All data collected will be stored securely on ECU premises and kept for 10 years after the completion of the project and then destroyed.

Participation in the Study

Participation in this research is entirely voluntary and you may refuse to participate or withdraw at anytime without adverse consequences.

If you have any questions about the research project or require further information you may contact the following:

Student Researcher: Harry Banyard

Telephone: 0439 377 603

Email: h.banyard@ecu.edu.au

Principal Supervisor: Dr. Greg Haff

Telephone: (08) 6 304 5655

Email: g.haff@ecu.edu.au

Secondary Supervisor: Prof. Ken Nosaka

Telephone: (08) 6 304 5655

Email: k.nosaka@ecu.edu.au

If you have any ethical concerns with regards to your participation in this study you may contact:

Research Ethics Officer: Kim Gifkins

Phone: (08) 9304 2170

Address: Human Research Ethics Committee, Edith Cowan University, 100 Joondahup Drive, Joondahup WA, 6027

Email: research.ethics@ecu.edu.au

Thank you for your time,

Yours sincerely,

Harry Banyard

APPENDIX C: INFORMATION LETTER – CHAPTER 6:

STUDY 4

The reader should be aware that during the original proposal, study 4 was proposed as the second study of this thesis. However, when the study 1 data was analysed it became apparent that the analysis warranted further investigations.



Information Letter to Participants

Title of the Project: Acute effects of 4 experimental strength-training models on fatigue and total work completed

Study 2

Investigator: Harry Banyard (PhD Candidate)

Supervisors: Dr. Greg Haff and Professor Ken Nosaka

School of Exercise and Health Sciences
Edith Cowan University
270 Joondalup Drive, Joondalup WA 6027

Thank you for expressing an interest in the study. The purpose of this information letter is to provide you with an overview of the study in which you may participate in as a subject.

Purpose of the study

The purpose of this study is to determine the optimal velocity-based training method (the ascending/descending method or the velocity band method) by examining the acute effects of velocity-based training compared to traditional strength training on fatigue and changes in physical performance.

Background

Typically, the training intensity for traditional strength training is determined as a percentage of 1-repetition maximum (1RM) or a given maximum number of repetitions (10RM, 5RM etc.) where each exercise set may or may not be completed to concentric muscular failure. However, training to concentric muscular failure can induce excessive fatigue (reduced power production) and diminish the force generating capacity in subsequent sets leading to lower gains in strength and power adaptations, and subsequently, smaller increases in performance. Velocity-based strength training requires an individual to perform an exercise with maximal speed/velocity on the concentric movement, which can be accurately monitored using a device called a position transducer.

Theoretically, if an exercise is performed with maximal voluntary effort, the velocity of the movement will decline within a set as fatigue ensues. When individual repetitions are monitored with a position transducer the concentric movement velocity can decline. Ultimately, the monitoring of velocity is useful for strength and conditioning coaches and athletes in order to establish first whether the athlete is providing maximal effort and second the accumulated fatigue within a session and over time. Two popular methods of velocity-based training include; the ascending/descending method where the weight is adjusted after each set according to the maximal concentric velocity of the previous set and the velocity band method in which a set can be terminated when repetitions are not performed above a pre-determined mean concentric velocity. At present it is unknown whether either of these methods would elicit greater long-term adaptations to strength and power compared to a traditional strength-training program. Additionally, even though long-term adaptations in strength and power may occur from velocity-based training, the magnitude of force decline within a session is unclear using the different velocity-based training methods. Thus, investigating the acute decline in force following velocity-based training compared to traditional strength training is required in order to provide programmatic guidance to strength coaches who may chose to implement this novel method for prescribing resistance training intensity.

Methods

Participants

As a volunteer, you must have at least 6 months of strength-training experience, be able to back squat 150% of your body weight, and must be without any current musculoskeletal injuries. Data collected from you in this study will be kept in a secure cabinet on the university premises with only the chief investigator having access to the data. Prior to the onset of this study you must complete an informed consent form, medical questionnaire and pre-exercise checklist.

Procedure

As a participant you will be required to visit the laboratory on six separate sessions 48 – 72 hours apart for the duration of approximately 45 mins/session at Edith Cowan University, Joondalup Campus, commencing in the strength lab, building 19, room 19.149. The first session will be used to familiarise you with the testing procedures, recording of height, weight, and completion of all required documentation. Session 2 will require you to perform a 1RM back squat assessment, but sessions 3 – 6 you will complete the four experimental protocols (Table 1) in a randomised order. Electromyography (EMG) electrodes, used to measure muscle activation, will be applied prior to the warm-up and placed on the skin surface of 3 thigh muscles and the gluteus ~~maximus~~ of the right

leg. A semi-permanent ink marker will be used to establish each electrode site.

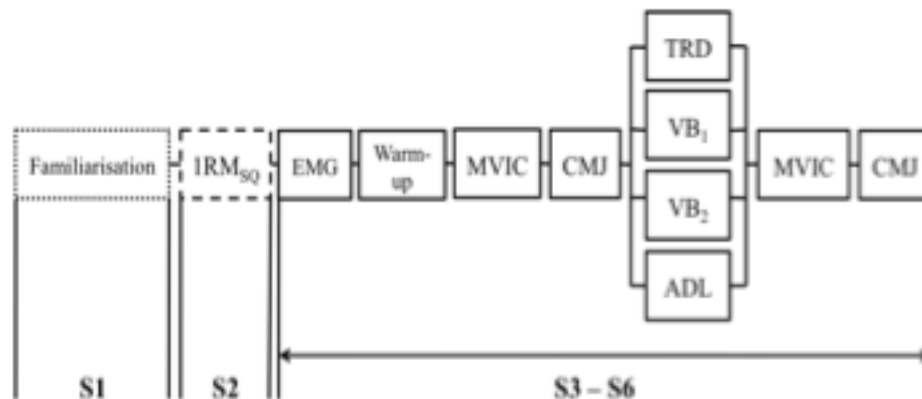


Figure 1. Study 2 experimental testing order for sessions 1 - 6 (S1, S2, S3, S4, S5, and S6). Experimental protocols include traditional (TRD), velocity band 1 (VB₁), velocity band 2 (VB₂) and ascending/descending load (ADL).

Following the warm-up and immediately after the experimental protocol, you will be required to perform 3 maximal voluntary isometric squat contractions and 3 countermovement jumps. Two minutes passive recovery (sitting in a chair) will be given between experimental sets, isometric squat and countermovement jump attempts.

1RM Back Squat

At the beginning of session 2 you will perform a warm-up procedure consisting of 3 minutes pedalling at 100W on a cycle ergometer followed by a squat protocol comprising 3 repetitions at 20% 1RM; 3 repetitions at 40% 1RM, 3 repetitions at 60% 1RM; 1 repetition at 80% 1RM and 1 repetition at 90% 1RM. On completion of the warm-up the 1RM back squat assessment will be performed. For every squat repetition attempted you will be instructed to perform the downward (eccentric) phase at a consistent, self-selected speed but to perform the upward (concentric) phase as fast and explosive as possible. Regarding rest periods, two minutes passive recovery will be given between warm-up sets and three minutes between 1RM back squat attempts. The Edith Cowan University Human Research Ethics Committee has approved this study.

Experimental Protocol

The experimental protocols include traditional (TRD) as listed in Table 1; velocity band 1 (VB₁) where 25 repetitions are completed with sets being terminated once a pre-determined 20 % decline

in average velocity is not attained (Table 1); velocity band 2 (VB₂) comprising 5 sets of unlimited repetitions where sets are terminated identically to VB₁ (Table 1); and the ascending/descending load (ADL) where a pre-determined average velocity for an 80% 1RM load will be selected for the initial set with the load for the subsequent sets being adjusted according to the average velocity of the previous set (Table 1).

Table 1. Study 2 experimental protocols. Traditional (TRD), velocity band 1 (VB₁), velocity band 2 (VB₂), or ascending/descending load (ADL). '?' denotes an unknown number which will be established during the experimental protocol.

Group	Load (%1RM)	Sets	Reps	Total Reps	Set Completion	Rest Period (s)
TRD	80	5	5	25	Forced completion	120
VB ₁	80	?	?	25	20% Velocity decline	120
VB ₂	80	5	?	?	20% Velocity decline	120
ADL	Start @ 80	5	5	25	Adjust load each set/ maintain velocity	120

Electromyography

Muscle activity from the ~~vastus lateralis~~, ~~vastus medialis~~, ~~rectus femoris~~ and ~~gluteus maximus~~ will be taken from your right leg during all back squat, isometric squat and countermovement jump repetitions. A disposable electrode will be attached to the skin of each site after the skin surface has been prepared (shaved, abraded, and alcohol swabbed).

Maximal Isometric Squat

For the isometric squat contractions, you will be positioned with a knee angle of 100 degrees underneath a barbell placed in a fixed position on the power rack, and asked to push as hard and fast as you can against the force platform for 3 seconds.

Countermovement Jump

For the countermovement jump, 30% of your 1RM back squat load will be used with the barbell placed in the same position on the shoulders as the back squat. You will be instructed to jump as high as possible for each repetition.

Potential Risks

IRM testing is considered extremely safe, however, an increased risk of injury can occur if IRM tests are performed incorrectly or by novice athletes who lack the technical skills required to perform the test. To minimise potential risks all participants will be screened for contraindications to exercise and must demonstrate proficiency with the back squat exercise. Researchers with extensive experience will monitor all testing sessions. Other precautions include a familiarisation session to instruct participants on correct technique and testing methods; the use of safety racks; and the addition of two spotters standing either side of the barbell ready to assist should a failed lift occur. Lastly, when the EMG electrodes are placed on the skin surface, sandpaper must be lightly applied to the skin, which may cause some skin irritation but the risk is considered minimal and causes little to no discomfort to the participant.

Potential Benefits

The IRM test is considered a valuable performance assessment often conducted on a per fee basis when consulting athletes. In addition, each testing session you will receive free personal training on correct squatting technique. Moreover, by taking part in this study you will be able to prescribe accurate loads for the back squat exercise from your IRM test. You will also have the chance to learn how the IRM can be estimated from the warm-up lifts and observe how current research techniques are performed while gaining an insight into the test involved. A summary of results for this study will be provided to you on request.

Privacy and Confidentiality

All information collected during this research remains confidential and will not be used for any other purpose other than this study. All data collected will be stored securely on ECU premises and kept for 10 years after the completion of the project and then destroyed.

Participation in the Study

Participation in this research is entirely voluntary and you may refuse to participate or withdraw at anytime without adverse consequences.

The Edith Cowan University Human Research Ethics Committee has approved this study but if you have any further questions about the research project or require further information you may contact the following:

Student Researcher: Harry Banyard
Telephone: 0439 377 603
Email: h.banyard@ecu.edu.au

Principal Supervisor: Dr. Greg ~~Haff~~
Telephone: (08) 6 304 5416
Email: g.haff@ecu.edu.au

Secondary Supervisor: Prof. Ken Nosaka
Telephone: (08) 6 304 5655
Email: k.nosaka@ecu.edu.au

If you have any ethical concerns with regards to your participation in this study you may contact:

Research Ethics Officer: Kim ~~Giffins~~
Phone: (08) 9304 2170
Address: Human Research Ethics Committee, Edith Cowan University, 100 Joondalup Drive,
Joondalup WA, 6027
Email: research.ethics@ecu.edu.au

Thank you for your time,

Yours sincerely,

Harry Banyard

APPENDIX D: INFORMATION LETTER – CHAPTER 7: STUDY 5

The reader should be aware that Study 5 training study in this thesis project was initially proposed as Study 3 in the original proposal.



Information Letter to Participants

Title of the Project: Chronic Effects of VBT compared to TRD on Strength and Power

Study 3

Investigator: Harry Banyard (PhD Candidate)

Supervisors: ~~Dr. Greg Haff~~ and Professor Ken ~~Nosaka~~

School of Exercise and Health Sciences
Edith Cowan University
270 Joondalup Drive, Joondalup WA 6027

Thank you for expressing an interest in the study. The purpose of this information letter is to provide you with an overview of the study in which you may participate in as a subject. The Edith Cowan University Human Research Ethics Committee has approved this study.

Background

Briefly, velocity-based strength training is a method of monitoring the movement speed for exercises performed in the gym in an attempt to quantify effort, the amount of work completed, and avoid excessive fatigue. This is obtained in a similar way to GPS monitoring of an athlete's conditioning sessions, where the GPS device quantifies running speeds and distance covered, among other variables in order to avoid excessive fatigue.

Research suggests for strength-trained individuals to obtain maximal gains in strength and power, it is ill advised to perform sets to exhaustion (failure). When lifting weights in the gym, traditional strength training requires an individual to perform exercises with predetermined sets/repetitions/intensities allowing for minimal program flexibility, regardless of how fatigued the individual. If maximal effort is given, the lifting speed (velocity) will decline when an individual fatigues. Using specialised equipment, we can monitor the barbell speed for a given exercise and modify the amount of repetitions performed based on the amount of decline in movement velocity. This is known as velocity based strength training.

Purpose of the study

The purpose of this study is to investigate the effects of velocity-based strength training compared to traditional strength training for the back squat exercise on changes in strength, power and markers of sports performance over a 6-week training intervention.

Participants

As a volunteer, you must have at least 6 months of strength-training experience, be able to back squat 150% of your body weight, and must be without any current musculoskeletal injuries. Data collected from you in this study will be kept in a secure cabinet on the university premises with only the chief investigator having access to the data. Prior to the onset of this study you must complete an informed consent form, medical questionnaire and pre-exercise checklist.

Week 1 & 8: Pre- & Post- Testing Procedure

You will be required to visit the strength laboratory for 3 sessions in week 1 and week 8. Testing order is listed below for sessions 1-3. For session 2, electromyography (EMG) electrodes, used to measure muscle activation, will be applied prior to the warm-up for the isometric squat, countermovement jump and back squat lifts up to 90% of 1RM. The electrodes will be placed on the skin surface of 3 thigh muscles and the gluteus ~~maximus~~ of the right leg. A semi-permanent ink marker will be used to establish each electrode site.

Familiarisation Session:

- Introduction to study & completion of documents.

Session 1:

- Warm-up,
- 1RM (estimated sub-max lifts @ 20, 40, 60, 80, 90% of 1RM).

Session 2:

- EMG,
- Warm-up,
- ISO squat,
- CMJ (30% of 1RM),
- ~~back~~ squat lifts (20, 40, 60, 80, 90% of 1RM).

Session 3:

- 20m sprint,
- ~~505~~ agility test.

Week 2 – 7: Training Procedure

As a participant you will be placed into one of two groups (Table 2) and partake in a back squat training study where you will be required to attend three sessions per week for 6-weeks including three testing sessions performed in pre-, mid-, and post-training (Table 1). The weekly training loads for all groups are indicated in Table 1. If you are placed in the traditional strength training (TRD) group your prescribed load for that session will be based on your pre-testing 1RM back squat. However, the training load for the three velocity-based strength-training groups will be based on your predicted 1RM back squat obtained from the warm-up sets performed in each session. The familiarisation session will be used to inform you of the testing procedures, recording of height, weight, and completion of all required documentation. Following the familiarisation session, all baseline tests will be conducted prior to the first week of training.

Table 1. Study 3 training sessions will be performed on Monday, Wednesday and Friday.

Weekly Training Loads (%1RM)								
	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8
All Groups	PreTest	75	77.5	80	82.5	85	75	PostTest

Experimental Groups

The experimental groups include traditional (TRD) as listed in Table 2, and velocity band group (VB) where 25 repetitions are completed with sets being terminated once a pre-determined 20% decline in average velocity is not attained (Table 2).

Table 2. Study 3 experimental groups and exercise session plan. '?' denotes an unknown number which will be established during the experimental protocol.

Back Squat Session Plan					
Group	Sets	Reps	Total Reps	Set Completion	Rest Period (s)
TRD	5	5	25	Forced completion	120
VB	?	?	25	20% Velocity decline	120

Electromyography

Muscle activity from the vastus lateralis, vastus medialis, rectus femoris and gluteus maximus will be taken from your right leg during all back squat, isometric squat and countermovement jump repetitions. A disposable electrode will be attached to the skin of each site after the skin surface has

been prepared (shaved, abraded, and alcohol swabbed).

1RM Back Squat

At the beginning of session 1 you will perform a warm-up procedure consisting of 3 minutes pedalling at 100W on a cycle ergometer followed by a squat protocol comprising 3 repetitions at 20% 1RM; 3 repetitions at 40% 1RM, 3 repetitions at 60% 1RM; 1 repetition at 80% 1RM and 1 repetition at 90% 1RM. On completion of the warm-up the 1RM back squat assessment will be performed. For every squat repetition attempted you will be instructed to perform the downward (eccentric) phase at a consistent, self-selected speed but to perform the upward (concentric) phase as fast and explosive as possible. Regarding rest periods, three minutes passive recovery will be given between sets.

Isometric Back Squat

For the isometric squat, you will be positioned on a force platform underneath a barbell placed in a fixed position on the power rack with a knee angle of 100 degrees. You will be required to push as hard and fast as possible against the force platform for 3 repetitions with 2 minutes recovery between attempts.

Countermovement Jump

For the countermovement jump, a barbell with 30% of your pre-test 1RM will be placed in the same position on the shoulders as the back squat. You will be asked to "jump as high as possible" for each attempt. Three countermovement jumps will be performed with 2 minutes recovery between attempts.

20-metre Sprint Test

As a participant you will be instructed to place your front foot as close to the start line as possible without touching it and attempt the 20m sprint three times. You will be asked to run as fast and hard as possible. Timing gates will be set at 0m, 5m, 10m and 20m intervals.

Potential Risks

1RM testing is considered extremely safe, however, an increased risk of injury can occur if 1RM tests are performed incorrectly or by novice athletes who lack the technical skills required to perform the test. To minimise potential risks all participants will be screened for contraindications to exercise and must demonstrate proficiency with the back squat exercise. Researchers with

extensive experience will monitor all testing sessions. Other precautions include a familiarisation session to instruct participants on correct technique and testing methods; the use of safety racks; and the addition of two spotters standing either side of the barbell ready to assist should a failed lift occur. Lastly, when the EMG electrodes are placed on the skin surface, sandpaper must be lightly applied to the skin, which may cause some skin irritation but the risk is considered minimal and causes little to no discomfort to the participant.

Potential Benefits

The 1RM test is considered a valuable performance assessment often conducted on a per fee basis when consulting athletes. In addition, each testing session you will receive free personal training on correct squatting technique and you are likely to increase your maximal leg strength and size with the added bonus of having 3 free body composition assessments. Moreover, by taking part in this study you will be able to prescribe accurate loads for the back squat exercise from your 1RM test. You will also have the chance to learn how the 1RM can be estimated from the warm-up lifts and observe how current research techniques are performed while gaining an insight into the test involved. A summary of results for this study will be provided to you on request.

Privacy and Confidentiality

All information collected during this research remains confidential and will not be used for any other purpose other than this study. All data collected will be stored securely on ECU premises and kept for 10 years after the completion of the project and then destroyed.

Participation in the Study

Participation in this research is entirely voluntary and you may refuse to participate or withdraw at anytime without adverse consequences.

The Edith Cowan University Human Research Ethics Committee has approved this study but if you have any further questions about the research project or require further information you may contact the following:

Student Researcher: Henry Banyard

Telephone: 0439 377 603

Email: h.banyard@ecu.edu.au

Principal Supervisor: ~~Dr. Greg Haff~~

Telephone: (08) 6 304 5416

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Secondary Supervisor: ~~Prof. Ken Nosaka~~

Telephone: (08) 6 304 5655

Email: k.nosaka@ecu.edu.au

If you have any ethical concerns with regards to your participation in this study you may contact:

Research Ethics Officer: Kim ~~Gilkins~~

Phone: (08) 9304 2170

Address: Human Research Ethics Committee, Edith Cowan University, 100 Joondalup Drive, Joondalup WA, 6027

Email: research.ethics@ecu.edu.au

Thank you for your time,

Yours sincerely,

Harry Banyard

APPENDIX E: INFORMED CONSENT FORM



Subject Informed Consent Form

I _____ consent to participating in the research project entitled:

“The Effects of Velocity-based Training on Fatigue, Strength and Power”

- I have carefully read, and clearly understand the content contained within the information letter and consent form.
- I agree to participate in this study, and provide my consent freely, without any undue pressure or expectation.
- I understand that all study procedures will be performed as outlined in the information sheet, a copy of which I have retained for my own records.
- I have had any and all questions answered to my satisfaction.
- All questionnaires related to this study have been completed to the best of my knowledge.
- I am aware that I may withdraw from this study at any stage, without any reason or prejudice.
- I agree that the data collected from this study may be published, providing my name and any information containing my identity is removed. This includes data related to your 1-repetition maximum back squat, and other variables associated with this assessment as outlined in the information letter.

The researcher certifies that the subject has a full understanding of the procedures and their involvement as a participant, as outlined in this form. The subject has provided verbal confirmation of their understanding, which meets the researchers satisfaction prior to signing the form.

Participant Name _____ Date (DD/MM/YYYY) _____

Researchers Name _____ Date (DD/MM/YYYY) _____

Signatures (Participant) _____ (Researcher) _____

APPENDIX F: MEDICAL QUESTIONNAIRE



Medical and Exercise Questionnaire

Project Title: The Effects of Velocity-based Training on Fatigue, Strength and Power.

The following questionnaire is designed to establish a background of your resistance training history, medical history, and identify any injury and/or illness that may influence your testing and performance. Please answer all questions as accurately as possible, and if you are unsure about any aspect of this form, please ask for clarification. All information provided is strictly confidential.

Personal Details

Name: _____

Date of Birth (DD/MM/YYYY): _____

PART A

1. In an average week how often would you perform lower body resistance training?

2. When was the last time you performed the back squat exercise? _____
3. What is the maximum amount of weight you have lifted in the full back squat exercise _____ kg; and when was this achieved? _____ (Date: DD/MM/YYYY)
4. Do you believe you can currently lift at least 1.5 times your body mass?
Y / N _____

PART B: YES / NO DETAILS

1. Are you a regular smoker, or have you quit in the last 6 months? Y / N _____
2. Did a close family member have heart disease or surgery, or stroke before the age of 60 years?
_____ Y / N _____
3. Do you have, or have you ever been told you have blood pressure above 140/90 mmHg, or do you currently take blood pressure medication? Y / N _____
4. Do you have, or have you ever been told you have a total cholesterol level above 5.2 mmol/L (200 mg/dL)? Y / N _____
5. Is your BMI (weight/height) greater than 30? Y / N _____

PART C YES / NO DETAILS

1. Have you ever had a serious asthma attack during exercise? Y / N _____
2. Do you have asthma that requires medication? Y / N _____
3. Have you had an epileptic seizure in the last 5 years? Y / N _____
4. Do you have any moderate or severe allergies? Y / N _____
5. Do you, or could you reasonably have an infectious disease? Y / N _____
6. Do you, or could you reasonably have an infection or disease that might be aggravated by exercise? Y / N _____

PART D YES / NO DETAILS

1. Are you currently taking any prescribed or non-prescribed medication? Y / N _____
2. Have you had, or do you currently have any of the following?
- Rheumatic Fever Y / N _____
 - Heart Abnormalities Y / N _____
 - Diabetes Y / N _____
 - Epilepsy Y / N _____
 - Recurring back pain that will make exercise problematic, or where exercise may aggravate pain? Y / N _____
 - Recurring neck pain that will make exercise problematic, or where exercise may aggravate pain? Y / N _____
 - Neurological disorders that would make exercise problematic, or where exercise may aggravate the condition? Y / N _____
 - Neuromuscular disorders that would make exercise problematic, or where exercise may aggravate the condition? Y / N _____
 - Recurring muscle/joint injuries that would make exercise problematic, or where exercise may aggravate the condition? Y / N _____

- A burning or cramping sensation in your legs when walking short distances?

Y / N _____

- Chest discomfort, unreasonable breathlessness, dizziness or fainting, or blackouts during exercise?

Y / N _____

PART E YES / NO DETAILS

1. Have you had any influenza in the last week? Y / N _____

2. Do you currently have an injury that might affect, or be affected by exercise?

Y / N _____

3. Have you had any minor or major injuries in the past 3 months? Y / N _____ If so, please list. Has this injury stopped you training or competing in one or more sessions? If so, how many? _____

4. Is there any other condition not previously mentioned that may affected your ability to participate in this study? Y / N _____

Declaration – (to be signed in the presence of the researcher)

I acknowledge that the information provided in this form, is to the best of my knowledge, a true and accurate indication of my current state of health.

Participant

Name: _____ Date (DD/MM/YYYY): _____

Signature: _____

Researcher

Name: _____ Date (DD/MM/YYYY): _____

Signature: _____

APPENDIX G: PUBLICATION – CHAPTER 3: STUDY 1

International Journal of Sports Physiology and Performance, 2017, 12, 1170-1176
https://doi.org/10.1123/ijsp.2016-0627
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Human Kinetics
ORIGINAL INVESTIGATION

Validity of Various Methods for Determining Velocity, Force, and Power in the Back Squat

Harry G. Banyard, Ken Nosaka, Kimitake Sato, and G. Gregory Haff

Purpose: To examine the validity of 2 kinematic systems for assessing mean velocity (MV), peak velocity (PV), mean force (MF), peak force (PF), mean power (MP), and peak power (PP) during the full-depth free-weight back squat performed with maximal concentric effort. **Methods:** Ten strength-trained men (26.1 ± 3.0 y, 1.81 ± 0.07 m, 82.0 ± 10.6 kg) performed three 1-repetition-maximum (1RM) trials on 3 separate days, encompassing lifts performed at 6 relative intensities including 20%, 40%, 60%, 80%, 90%, and 100% of 1RM. Each repetition was simultaneously recorded by a PUSH band and commercial linear position transducer (LPT) (GymAware [GYM]) and compared with measurements collected by a laboratory-based testing device consisting of 4 LPTs and a force plate. **Results:** Trials 2 and 3 were used for validity analyses. Combining all 120 repetitions indicated that the GYM was highly valid for assessing all criterion variables while the PUSH was only highly valid for estimations of PF ($r = .94$, $CV = 5.4\%$, $ES = 0.28$, $SEE = 135.5$ N). At each relative intensity, the GYM was highly valid for assessing all criterion variables except for PP at 20% ($ES = 0.81$) and 40% ($ES = 0.67$) of 1RM. Moreover, the PUSH was only able to accurately estimate PF across all relative intensities ($r = .92-.98$, $CV = 4.0-8.3\%$, $ES = 0.04-0.26$, $SEE = 79.8-213.1$ N). **Conclusions:** PUSH accuracy for determining MV, PV, MF, MP, and PP across all 6 relative intensities was questionable for the back squat, yet the GYM was highly valid at assessing all criterion variables, with some caution given to estimations of MP and PP performed at lighter loads.

Keywords: velocity-based training, GymAware, PUSH band, athlete monitoring

Assessments of velocity, force, and power are often employed to monitor training-induced adaptations.¹⁻³ For elite athletes, changes in these measures can be minor yet significant. As a consequence, equipment used to monitor changes in performance should be precise. In a laboratory-based environment, linear position transducers (LPTs) are often used to accurately measure velocity, force plates ascertain ground-reaction forces, and a combination of LPTs and force plates can be employed to estimate power output.⁴⁻⁷ Laboratory-based testing is considered the “gold standard” for data collection, yet it is limited due to the large expense, transportation difficulties, and practical complications that can arise from testing with large groups of team-sport athletes. Consequently, several field-based devices including portable LPTs, accelerometers, and inertial sensors (combination of accelerometer and gyroscope) have been invented to overcome these limitations.⁸⁻¹¹ However, it is important to determine the devices’ accuracy to ensure that training decisions are not made as a result of device measurement error.

One LPT device scientifically determined to accurately assess kinematic variables is the GymAware (GymAware Power Tool [GYM], Kinetic Performance Technologies, Canberra, Australia).^{5,7,12} This portable field-based device is a popular tool used to monitor and test athletes. However, it may be cost prohibitive for nonprofessional sporting teams, thus limiting its use by coaches

and athletes. Furthermore, since it requires the use of a cable/wire attachment to the barbell, it can be limited in the number of lifting exercises that it can effectively quantify. Consequently, there has been an increased interest in wireless measurement tools to assess kinematic variables without impeding lifting performance due to direct attachments.

Recently, a wearable inertia sensor (PUSH band, PUSH Inc, Toronto, Canada) was developed to measure velocity during resistance-training exercises. In addition, it has been suggested that force and power can be accurately estimated from the determined velocity of movement. Presently, only 2 studies have validated the PUSH, with 1 employing a Smith-machine exercise¹³ while the other investigated dumbbell exercises.¹⁴ Note that both studies suggested the PUSH accurately measured both mean and peak velocity. However, no previous study has examined the validity of the PUSH with the use of a large-mass free-weight exercise such as the back squat across a variety of training intensities. The PUSH is relatively inexpensive compared with the GYM, but since many sporting teams already have GYM technology, evaluating the accuracy of measurement devices such as the PUSH is highly beneficial. Therefore, the purpose of this study was to investigate the ability of 2 field-based devices to accurately measure velocity, force, and power in the back-squat exercise compared with laboratory-based testing equipment.

Methods

Participants

Ten male resistance-trained volunteers took part in this study (26.1 ± 3.0 y, 1.81 ± 0.07 m, 82.0 ± 10.6 kg). All participants could perform

Banyard is with the Centre for Exercise and Sport Science Research; Nosaka, the School of Exercise and Health Sciences; and Haff, the Dept of Strength & Conditioning, Edith Cowan University, Joondalup, WA, Australia. Sato is with the Dept of Exercise and Sport Science, East Tennessee State University, Johnson City, TN. Banyard (h.banyard@ecu.edu.au) is corresponding author.

RELIABILITY AND VALIDITY OF THE LOAD-VELOCITY RELATIONSHIP TO PREDICT THE 1RM BACK SQUAT

HARRY G. BANYARD, KAZUNORI NOSAKA, AND G. GREGORY HAFF

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ABSTRACT

Banyard, HG, Nosaka, K, and Haff, GG. Reliability and validity of the load-velocity relationship to predict the 1RM back squat. *J Strength Cond Res* 31(7):1897-1904, 2017 -This study investigated the reliability and validity of the load-velocity relationship to predict the free-weight back squat one repetition maximum (1RM). Seventeen strength-trained males performed three 1RM assessments on 3 separate days. All repetitions were performed to full depth with maximal concentric effort. Predicted 1RMs were calculated by entering the mean concentric velocity of the 1RM (V_{1RM}) into an individualized linear regression equation, which was derived from the load-velocity relationship of 3 (20, 40, 60% of 1RM), 4 (20, 40, 60, 80% of 1RM), or 5 (20, 40, 60, 80, 90% of 1RM) incremental warm-up sets. The actual 1RM (140.3 ± 27.2 kg) was very stable between 3 trials (ICC = 0.99; SEM = 2.9 kg; CV = 2.1%; ES = 0.11). Predicted 1RM from 5 warm-up sets up to and including 90% of 1RM was the most reliable (ICC = 0.92; SEM = 8.6 kg; CV = 5.7%; ES = -0.02) and valid ($r = 0.93$; SEE = 10.6 kg; CV = 7.4%; ES = 0.71) of the predicted 1RM methods. However, all predicted 1RMs were significantly different ($p \leq 0.05$; ES = 0.71-1.04) from the actual 1RM. Individual variation for the actual 1RM was small between trials ranging from -5.6 to 4.8% compared with the most accurate predictive method up to 90% of 1RM, which was more variable (-5.5 to 27.8%). Importantly, the V_{1RM} (0.24 ± 0.06 m·s⁻¹) was unreliable between trials (ICC = 0.42; SEM = 0.05 m·s⁻¹; CV = 22.5%; ES = 0.14). The load-velocity relationship for the full depth free-weight back squat showed moderate reliability and validity but could not accurately predict 1RM, which was stable between trials. Thus, the load-velocity relationship 1RM prediction method used in this study cannot

accurately modify seasonal training loads because of large V_{1RM} variability.

KEY WORDS psychometric analysis, maximal strength, strength testing, velocity based training, linear position transducer

INTRODUCTION

The one repetition maximum (1RM) assessment is a well-established, valid, and reliable method of determining maximal strength (13,20). However, the overall time commitment associated with performing 1RM assessments for large squads of team sport athletes can be problematic. In addition, maximal strength has been reported to change rapidly (23), and frequent testing can take valuable time away from training. Consequently, regression equations to estimate 1RM, using the maximum number of repetitions performed to concentric muscular failure with a submaximal load, have been established (4,5,21,24,26). However, the accuracy of these equations may vary according to the type of exercise, amount of repetitions completed, gender, and training status (13,19,33). Furthermore, if a strength coach wanted to frequently monitor changes in maximal strength using 1RM prediction equations, the requisite sets performed to exhaustion may result in excessive fatigue and diminish the force generating capacity in subsequent sets performed within the same training session leading to lower strength gains and power adaptations (15,16,28,29). Therefore, an alternate less fatiguing method for determining an individual's maximal strength is required.

Because of the advancement in kinetic and kinematic transducer technologies, it is now possible to accurately measure bar velocity (11,27). Specifically, 3 methods to quantify concentric movement velocity include peak concentric velocity, mean concentric velocity, and mean propulsive velocity (2,8,11,28). Importantly, even though peak concentric velocity is a pertinent measure for explosive-type resistance training exercises such as bench throws and countermovement jumps, mean concentric velocity is believed to better represent the different velocities observed through the entire phase of nonaerial movements like the squat (8,16,17,27,31). That being said, Sánchez-Medina,

Address correspondence to Harry G. Banyard, h.banyard@ecu.edu.au 31(7)/1897-1904

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APPENDIX I: PUBLICATION – CHAPTER 5: STUDY 3

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Human Kinetics 
ORIGINAL INVESTIGATION

The Reliability of Individualized Load–Velocity Profiles

Harry G. Banyard, Kazunori Nosaka, Alex D. Vernon, and G. Gregory Haff

Purpose: To examine the reliability of peak velocity (PV), mean propulsive velocity (MPV), and mean velocity (MV) in the development of load–velocity profiles (LVP) in the full-depth free-weight back squat performed with maximal concentric effort. **Methods:** Eighteen resistance-trained men performed a baseline 1-repetition maximum (1-RM) back-squat trial and 3 subsequent 1-RM trials used for reliability analyses, with 48-h intervals between trials. 1-RM trials comprised lifts from 6 relative loads including 20%, 40%, 60%, 80%, 90%, and 100% 1-RM. Individualized LVPs for PV, MPV, or MV were derived from loads that were highly reliable based on the following criteria: intraclass correlation coefficient (ICC) >.70, coefficient of variation (CV) ≤10%, and Cohen *d* effect size (ES) <0.60. **Results:** PV was highly reliable at all 6 loads. MPV and MV were highly reliable at 20%, 40%, 60%, 80%, and 90% but not 100% 1-RM (MPV: ICC = .66, CV = 18.0%, ES = 0.10, SEM = 0.04 m·s⁻¹; MV: ICC = .55, CV = 19.4%, ES = 0.08, SEM = 0.04 m·s⁻¹). When considering the reliable ranges, almost perfect correlations were observed for LVPs derived from PV_{20–100%} ($r = .91–.93$), MPV_{20–90%} ($r = .92–.94$), and MV_{20–90%} ($r = .94–.95$). Furthermore, the LVPs were not significantly different ($P > .05$) between trials or movement velocities or between linear regression versus 2nd-order polynomial fits. **Conclusions:** PV_{20–100%}, MPV_{20–90%}, and MV_{20–90%} are reliable and can be utilized to develop LVPs using linear regression. Conceptually, LVPs can be used to monitor changes in movement velocity and employed as a method for adjusting sessional training loads according to daily readiness.

Keywords: peak velocity, mean velocity, mean propulsive velocity, back squat, velocity-based training

Resistance-training intensity is typically derived from a percentage of an actual or estimated 1-repetition maximum (1-RM) assessment.¹ Once a 1-RM load is determined, a strength coach can periodize the relative intensity of the training sessions to maximize adaptation and allow for recovery.² Although this method is relatively simple and requires no monitoring equipment, an athlete's maximal strength can increase rapidly,³ suggesting that continued prescription of relative loads from a baseline 1-RM could compromise adaptation. Alternatively, an athlete who may be excessively fatigued for a prescribed training session is still required to lift a load, which may exacerbate fatigue and prolong recovery time. Therefore, it is necessary to establish a more precise and less demanding method of monitoring an athlete's training that can be used to modify exercise intensity when necessary.

Research has demonstrated an inverse linear relationship exists between load and velocity (load–velocity profile [LVP]), meaning that if maximal effort is given for the concentric phase of a lift, heavier loads cannot be lifted with the same velocity as lighter loads.^{4–8} Furthermore, if maximal concentric effort is provided within a training set for a consistent range of motion, velocity will decline as concentric muscular fatigue ensues.⁹ Currently, it is not known what occurs to movement velocity between training sessions when an athlete is fatigued in nonballistic-type exercises, such as the barbell back squat. It is hypothesized that when an athlete is fatigued, he or she may perform repetitions with reduced movement velocity compared with his or her nonfatigued velocity. However, to monitor training-induced changes in movement

velocity, the reliability of movement velocity used to develop LVPs needs to be established. This is critical for a coach who needs to differentiate between true changes in an athlete's movement velocity resulting from fatigue or training-induced adaptation and the typical error observed between training sessions.

Previous studies have established LVPs for the prone pull-up, bench press, leg press, half squat, and full squat exercises.^{6,10,11} The LVP regression equations reported by Conceição et al¹⁰ and Gonzalez-Badillo and Sanchez-Medina⁶ were obtained from the group mean of 15 and 56 subjects, respectively. It is important to discern that different athletes can produce unique movement velocities based on individual characteristics, such as their limb biomechanics and expression of fiber types.^{12,13} Therefore, group mean LVP equations may not be appropriate for accurate monitoring of individual athletes who generate faster or slower movement velocities than the group mean. Notably, Conceição et al¹⁰ and Gonzalez-Badillo and Sanchez-Medina⁶ did not report the baseline test-retest reliability of movement velocity used to develop the LVPs of the subjects. Therefore, it is difficult to establish the exact significance of their findings because the typical variation in movement velocity between testing sessions was not reported for their subjects in a nonfatigued state. However, a key finding from these studies was that LVPs are exercise specific. With this in mind, it is important to note that Conceição et al¹⁰ and Gonzalez-Badillo and Sanchez-Medina⁶ had subjects perform repetitions on a weight machine or a Smith machine with a 3- to 4-second pause between the eccentric and concentric phases of the maximal effort concentric contractions (pause method). Conceição et al¹⁰ suggest the pause between eccentric and concentric phases can minimize measurement error by removing the influence of the stretch-shortening cycle (SSC) from the concentric contraction. Although the findings of the 2 aforementioned studies are valuable, it is possible that their results are not ecologically valid with free-weight exercises utilizing the SSC that also involve vertical and some horizontal barbell movements.¹⁴ This is

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APPENDIX J: PUBLICATION ACCEPTANCE – CHAPTER 6: STUDY 4

"Comparison of Velocity-Based and Traditional 1RM-Percent-Based Prescription on Acute Kinetic and Kinematic Variables" by Banyard HG et al.
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Section: Original Investigation

Article Title: Comparison of Velocity-Based and Traditional 1RM-Percent-Based Prescription on Acute Kinetic and Kinematic Variables

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APPENDIX K: 2018 INTERNATIONAL CONFERENCE FOR STRENGTH TRAINING (ICST) POSTER

Comparison Between 6-Weeks Velocity-Based Training vs. 1RM-Percent-Based Training Effects on Strength & Power



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INTRODUCTION

This study compared the effects of velocity-based training (VBT) and one repetition maximum (1RM) percent-based training (PBT) on changes in strength, power and sprint times when groups were matched for sets and repetitions but differed in training load prescription.

METHODS

24-resistance-trained males performed 6-weeks of full depth free-weight back squats 3 times a week in a daily undulating format. PBT group (n=12) lifted with relative loads varying from 59%–85%1RM, whereas the VBT group (n=12) trained with loads that could be adjusted to achieve a target velocity from an Individualized load-velocity profile (LVP) that corresponded with 59%–85%1RM. Pre- and post-training assessments included 1RM, countermovement jump with 30%1RM (CMJ), 20m sprint (5m & 10m), and 505 change of direction test (COD) (Figure 1). Changes within and between groups were assessed by magnitude based inferences and a MANOVA.

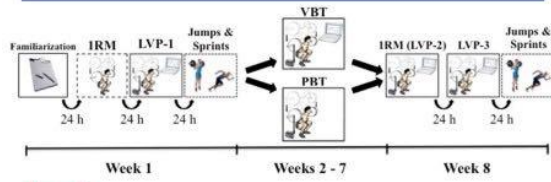


Figure 1. Overall experimental study design timeline.

Table 1. VBT and PBT within group comparisons for pre- and post-testing measure, differences, percent changes, and statistical analyses.

	VBT						
	Pre	Post	Absolute Δ	% Δ	p-value	ES	MBI
1RM (kg)	156.7 ± 20.9	153.6 ± 21.4	-17.0 ± 4.3	-11.3	2.25E ⁻⁰⁸	0.80	Almost Certainly
PV - CMJ (m·s ⁻¹)	2.50 ± 0.23	2.69 ± 0.25	0.19 ± 0.03	7.4	5.27E ⁻⁰⁸	0.79	Almost Certainly
PP - CMJ (W)	4527 ± 913	4869 ± 968	342 ± 70	7.7	2.87E ⁻⁰⁷	0.36	Almost Certainly
MV (m·s ⁻¹)	0.76 ± 0.07	0.76 ± 0.07	0.07 ± 0.02	6.5	2.71E ⁻⁰⁸	0.64	Almost Certainly
20%	1.29 ± 0.12	1.37 ± 0.13	0.08 ± 0.02	6.5	2.71E ⁻⁰⁸	0.64	Almost Certainly
40%	1.12 ± 0.07	1.20 ± 0.07	0.08 ± 0.03	7.4	1.13E ⁻⁰⁷	1.14	Almost Certainly
60%	0.90 ± 0.06	0.97 ± 0.08	0.07 ± 0.02	7.9	1.84E ⁻⁰⁷	0.99	Almost Certainly
80%	0.68 ± 0.07	0.76 ± 0.07	0.07 ± 0.04	11.6	1.12E ⁻⁰⁷	1.14	Almost Certainly
90%	0.50 ± 0.06	0.58 ± 0.06	0.08 ± 0.06	18.3	3.88E ⁻⁰⁹	1.33	Almost Certainly
1RM	0.24 ± 0.05	0.48 ± 0.06	0.25 ± 0.07	100.2	1.88E ⁻⁰⁸	4.00	Almost Certainly
5m Sprint (s)	1.16 ± 0.06	1.09 ± 0.06	0.07 ± 0.02	-6.5	7.77E ⁻⁰⁷	1.17	Almost Certainly
10m Sprint (s)	1.90 ± 0.08	1.83 ± 0.07	0.07 ± 0.03	-5.8	2.35E ⁻⁰⁷	0.93	Almost Certainly
20m Sprint (s)	3.20 ± 0.11	3.14 ± 0.12	0.06 ± 0.02	-1.8	7.640E ⁻⁰⁷	0.52	Almost Certainly
DL - COD (s)	2.32 ± 0.10	2.20 ± 0.10	-0.13 ± 0.04	-4.9	8.28E ⁻⁰⁷	1.20	Almost Certainly
NDL - COD (s)	2.38 ± 0.12	2.24 ± 0.10	-0.14 ± 0.07	-5.4	2.19E ⁻⁰⁷	1.27	Almost Certainly

	PBT						
	Pre	Post	Absolute Δ	% Δ	p-value	ES	MBI
1RM (kg)	135.2 ± 11.0	152.1 ± 12.8	19.1 ± 4.3	12.5	2.74E ⁻⁰⁸	1.41	Almost Certainly
PV - CMJ (m·s ⁻¹)	2.53 ± 0.19	2.63 ± 0.21	0.10 ± 0.02	4.0	3.79E ⁻⁰⁹	0.50	Almost Certainly
PP - CMJ (W)	4517 ± 617	4783 ± 634	266 ± 132	6.0	2.33E ⁻⁰⁷	0.42	Almost Certainly
MV (m·s ⁻¹)	0.76 ± 0.07	0.76 ± 0.07	0.06 ± 0.02	6.3	3.00E ⁻⁰⁷	0.69	Almost Certainly
20%	1.25 ± 0.11	1.33 ± 0.12	0.08 ± 0.03	6.3	3.00E ⁻⁰⁷	0.69	Almost Certainly
40%	1.08 ± 0.06	1.14 ± 0.07	0.08 ± 0.02	6.4	6.20E ⁻⁰⁷	0.92	Almost Certainly
60%	0.87 ± 0.06	0.93 ± 0.07	0.06 ± 0.02	6.9	6.84E ⁻⁰⁷	0.92	Almost Certainly
80%	0.65 ± 0.07	0.73 ± 0.07	0.08 ± 0.03	9.0	1.97E ⁻⁰⁷	1.14	Almost Certainly
90%	0.48 ± 0.07	0.55 ± 0.07	0.06 ± 0.03	13.8	8.99E ⁻⁰⁸	1.00	Almost Certainly
1RM	0.23 ± 0.04	0.44 ± 0.05	0.21 ± 0.10	89.7	3.63E ⁻⁰⁸	3.50	Almost Certainly
5m Sprint (s)	1.14 ± 0.06	1.10 ± 0.07	0.04 ± 0.01	-3.3	2.47E ⁻⁰⁷	0.61	Almost Certainly
10m Sprint (s)	1.90 ± 0.10	1.86 ± 0.10	0.04 ± 0.01	-2.0	1.25E ⁻⁰⁷	0.40	Almost Certainly
20m Sprint (s)	3.21 ± 0.16	3.18 ± 0.16	0.03 ± 0.01	-0.9	3.20E ⁻⁰⁷	0.19	Almost Certainly Not
DL - COD (s)	2.50 ± 0.10	2.21 ± 0.11	-0.09 ± 0.03	-3.6	6.93E ⁻⁰⁷	0.86	Almost Certainly
NDL - COD (s)	2.34 ± 0.10	2.25 ± 0.11	-0.09 ± 0.07	-3.5	1.53E ⁻⁰⁷	0.86	Almost Certainly

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RESULTS

VBT group had lower training loads ($p < 0.05$, $\sim 1.7\%$ 1RM; Figure 2A), and maintained faster repetitions during training ($p < 0.05$, mean velocity [MV] = 0.76 m/s vs 0.66 m/s; Figure 2B) that were perceived with less difficulty ($p < 0.05$, rating of perceived exertion = 5.1 vs 6.0; Figure 2D) compared to PBT group.

As seen in Table 1, VBT and PBT groups significantly improved their 1RM (VBT: 11.3% vs PBT: 12.5%), CMJ (VBT: 7.4% vs PBT: 6.0%), 20m sprint (VBT: -1.9% vs PBT: -0.9%), and COD (VBT: -5.4% vs PBT: -3.6%) without significant differences between groups.

However, likely favorable training effects were observed in 1RM for the PBT group, whilst VBT was likely favorable for the sprints, and possibly favorable for COD (Figure 3).

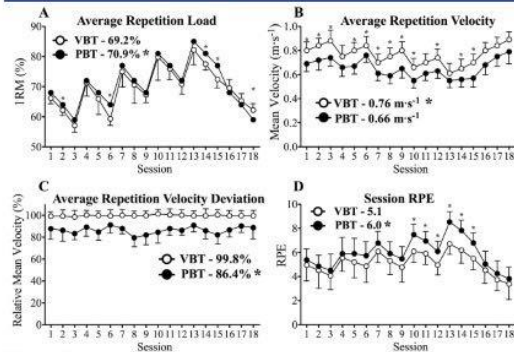


Figure 2. Training session values for (A) average repetition load (%1RM), (B) average repetition velocity, (C) average repetition velocity deviation compared to the intended velocity from the individualized load-velocity profile, (D) session rating of perceived exertion (RPE). * $p < 0.05$.

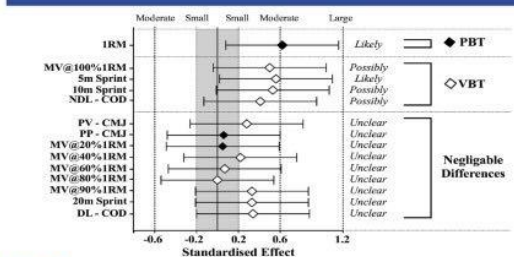


Figure 3. Favorable effect size comparisons for the changes in testing measures

CONCLUSIONS

Both training methods are similarly effective but VBT may be preferred by some individuals since it is perceived with less difficulty, and accounts for day-to-day fluctuations in an individual's performance. This could be beneficial for athletes who partake in numerous training modalities where fluctuations in strength and velocity may be exacerbated.

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APPENDIX L: RESPONSE TO EXAMINERS' COMMENTS

Appendix L is not included in this version of the theses