**Title:** A comparison of the FitroDyne and GymAware rotary encoders for quantifying peak and mean velocity during traditional multi-jointed exercises

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**This is a non-final version of an article published in final form in the Journal of Strength and Conditioning Research.**

## ABSTRACT

The FitroDyne and GymAware rotary encoders are being increasingly used in resistance training to monitor movement velocity, but how closely their velocity outcomes agree is unknown. Consequently, this study aimed to determine the level of agreement between the FitroDyne and GymAware for the assessment of movement velocity in three resistance training exercises. Fifteen males performed three repetitions of bench press, back squat and bent-over-row exercises at 10% one repetition maximum increments (from 20 to 80%). For each repetition, the FitroDyne and GymAware recorded peak and mean barbell velocity ($cm \cdot s^{-1}$). Though strongly correlated (r = 0.79 to 1.00), peak velocity values for the GymAware were significantly lower than the FitroDyne for all exercises and loads. Importantly, the random errors between the devices, quantified via Bland and Altman's 95% limits of agreement, were unacceptable, ranging from ± 3.8 to 25.9 $cm \cdot s^{-1}$. Differences in mean velocity were smaller (and non-significant for most comparisons) and highly correlated (r = 0.86 to 1.00) between devices. Notwithstanding smaller random errors than for the peak values, mean values still reflected poor agreement (random errors between ± 2.1 to 12.0 $cm \cdot s^{-1}$). These findings suggest that the FitroDyne and GymAware cannot record peak or mean velocity with acceptable agreement, and should neither be employed interchangeably nor their data compared.

**Key words**

Velocity, validity, agreement, bench press, squat, bent-over-row

## INTRODUCTION

Resistance training, particularly velocity based training, is widely used by applied practitioners for its positive impact on muscle function and potential to advance athletic/sporting performance (17,22). However, acute responses to resistance training can result in impaired muscle function which are manifest in velocity losses of ~13.1 to 63.3% (12,25). Nonetheless, when used longitudinally, resistance training programs can improve velocity by ~4 to 8% (26,29).

The use of force platforms and motion capture apparatus is generally considered the 'gold standard' method for assessing muscle function variables, though this method is not always cost-effective and its use is often limited to laboratory settings (7,30). Rotary encoders, accelerometers and linear position transducers have enabled practitioners and researchers to assess muscle function more efficiently, and have considerable potential to improve the quality of research (8,21) and applied work. Several studies have determined the validity of linear position transducers (5,7), rotary encoders (6,8) and accelerometers (4), notwithstanding, empirical findings remain equivocal. While some studies deem these methods valid for measuring velocity outcomes (4,7,8,20,23) others have questioned the accuracy of these measurement tools (5,6).

Recently, two commercially available rotary encoders, the FitroDyne and GymAware, have become increasingly popular in empirical research (8,10,11,15) and applied settings. Indeed, the use of these tools can aid the monitoring of resistance training and optimize training prescription (27). When attached to a subject or barbell, via a retractable cord (cord tension of < 200 g and 800 g for the FitroDyne and GymAware, respectively), rotary encoders convert displacement into an analogue reading (9). Both these rotary encoders use the optical encoding method whereby a light beam passes through a slot on a rotating disc. The FitroDyne samples at 100 Hz whereas the GymAware adopts a variable sampling rate that it then down-samples to 50 points per second. It is plausible that the different sampling methods of the GymAware and FitroDyne could alter the velocity outcomes they record. In order to give researchers and practitioners confidence to use such tools interchangeably and compare their findings, it is important to determine if they yield similar velocity measures for a given exercise. This can determine if these devices could be used interchangeably and could facilitate the comparison of findings from different studies.

Only one study has previously considered the agreement between two commercially available rotary encoders. Garnacho-Castano and colleagues (13) reported very high intra-class correlation coefficients (ICC; 0.96 to 0.99) and accompanied by moderate random errors (± 6.0 to 13.0 $cm \cdot s^{-1}$) for peak and mean velocity between the Tendo Weightlifting Analyser system and the T-Force Dynamic Measurement System during back squat and bench press exercises. However, the authors failed to expand on the practical significance of the within-subject differences (errors) observed. To facilitate researchers and practitioners confidence in these measurement tools it is important to determine if such tools can yield similar velocity outcomes for a given exercise. This could determine the extent to which the devices in question can be used interchangeably, enhancing knowledge in this area by facilitating the comparison of findings from different studies to be compared. Consequently, the purpose of the study was to determine the agreement between the FitroDyne and GymAware for the assessment of peak and mean velocity during bench press, squat and bent-over-row exercise.

## METHODS

*Experimental approach to the problem*

Subjects attended the laboratory on two occasions. The first session comprised habituation and maximal strength testing, during which anthropometric measurements (stature and body mass) were recorded. During the habituation, subjects performed multiple resistance trials and when their velocity plateaued, they were considered 'habituated' (3). Forty-eight hours later they returned and completed three repetitions of bench press, squat and bent-over-row, with 30 to 90 s rest between repetitions and exercises (9), at loads corresponding to 20 to 80% of individual one repetition maximum (1RM). These selected exercises are multi-jointed compound movements, which are commonly incorporated into resistance training programs (17).

*Subjects*

Fifteen healthy males (age 31.4 ± 12.2 y, mass 84.6 ± 14.8 kg, stature 1.8 ± 0.1 m, with relative strength for bench press, squat and bent-over-row of 1.14 ± 0.15, 1.51 ± 0.44, 1.08 ± 0.21 $kg{\cdot}bm^{-1}$, respectively), who were asymptomatic of illness or injury, were recruited to the study using convenience sampling. All subjects had a minimum of two years resistance training and used bench press, squats and bent-over-rows as part of their resistance training programs. Subjects provided written informed consent and the study received approval from the institutional Research Ethics Committee.

*Procedures*

Maximum strength for bench press and bent-over-row was assessed using a direct 1RM protocol on a bearing-supported linear raise Smith machine (Smith machine standard, Perform Better, Leicester, UK) consistent with the methods of Stock et al. (28). Squat 1RM was predicted from a five-repetition maximum (5RM) protocol in a manner outlined previously (24) and from the equation:

$$1RM (kg) = 1.0970 \times (5RM\ load\ [kg]) + 14.2546$$

This prediction equation has been deemed an accurate estimate of 1RM ($R^2$ = 0.988, standard error of estimate = 13.51 kg) by Reynolds et al. (24).

During the testing protocol, peak and mean velocity ($cm \cdot s^{-1}$) were assessed at 20, 30, 40, 50, 60, 70 and 80% 1RM on bench press, squat and bent-over-row in a randomized order. For each repetition, subjects performed the concentric component in an explosive manner, with the aim of trying to produce maximum velocity. The FitroDyne (Fitronic, Bratislava, Slovakia) and GymAware (Kinetic Performance Technology, Canberra, Australia) were attached directly under the bar on a Smith machine via their cords. The inter-repetition reliability for the testing session was high for bench press (coefficient of variation (CV%) = 1.1 to 7.5) and bent-over-row (CV% = 1.6 to 7.1; Table 1). Squat demonstrated generally favorable reliability (CV% = 1.6 to 9.2), except for mean velocity between repetitions 2 and 3 at 80% 1RM assessed by the GymAware (CV% = 11.2). A Smith machine was incorporated to reduce deviations from the vertical direction. The rotary encoders were simultaneously positioned at opposite ends of the barbell so as not to affect subject's standardized grip width. This was deemed an acceptable approach as the Smith machine would limit asymmetrical movement of the barbell.

[Table 1 about here]

*Statistical analyses*

The average value of peak and mean velocity from the three repetitions performed with the same load were used to assess the level of agreement between the FitroDyne and GymAware. Assumptions of normal distribution were found to be satisfied using the Shapiro-Wilk statistic ($p > 0.05$). A two-way analysis of variance (ANOVA) was employed to assess the variability of peak and mean velocity with respect to the method (FitroDyne and GymAware) and load (20-80% 1RM) factors. Where appropriate paired samples *t*-tests were used to locate specific pairwise differences. Having established that the differences (errors) were found to be homoscedastic, the random (within-subject) error between the devices was quantified using Bland and Altman's 95% limits of agreement (LoA) technique (bias ± (1.96 x $SD_{diff}$)) and expressed in the units of the velocity measures. Though not indicative of agreement (19), Pearson correlation coefficients (*r*) were also calculated to facilitate comparisons with the few previous related investigations (2,13,14,20). The strength of the correlations was interpreted using the following criteria: trivial (< 0.10), small (0.10-0.29), moderate (0.30-0.49), high (0.50-0.69), very high (0.70-0.90) or practically perfect (> 0.90) (18). Alpha was set at 0.05. All data were analyzed using SPSS software (version 22, IBM SPSS Inc, Chicago, IL, USA).

## RESULTS

The descriptive statistics for peak and mean velocity for the FitroDyne and GymAware are provided in Figure 1.

[Figure 1 about here]

*Peak velocity*

A significant load effect was identified for peak velocity for all exercises ($p < 0.001$). Likewise there was method effect in which the GymAware produced systematically lower values on average across all seven loads for the three exercises ($p < 0.05$). No load x method interactions were observed, apart from the squat peak velocity ($p < 0.05$), though as evident in Figure 1B, there was no clear explanatory pattern. The correlations for peak velocity were typically high (0.79 to 0.99, 0.94 to 1.00 and 0.91 to 0.98 for bench press, squat and bent-over-row, respectively), whereas the LoA were poorer (see Table 1), reflecting individual variability of up to ± 25.9, 9.3, and 25.0 $cm \cdot s^{-1}$ for bench press, squat, and bent-over-row, respectively.

*Mean velocity*

For the mean velocity, the average values varied across loads, but the effect of method was generally less obvious than for peak values (above), being significant only for mean velocity during the squat exercise ($p < 0.001$). Moreover, the pattern of values (i.e. interaction effect) across the loads was consistent for the FitroDyne and GymAware methods ($p > 0.05$) for each exercise. Between-method correlations were again high for all exercises ($r = 0.86$ to 0.99), whilst the LoA were narrower (improved) relative to the peak values, but reflecting individual variability of up to ± 13.6, 7.5, 12.0 $cm \cdot s^{-1}$ for mean velocity for bench press, squat, and bent-over-row, respectively (see Table 1).

[Table 2 about here]

## DISCUSSION

Consistent with the aim of this study, the main finding was that the velocity outcomes measured during traditional multi-jointed resistance exercises, by two commercially available rotary encoders, do not present an acceptable level of agreement. In particular, peak velocity values were markedly and consistently lower in the GymAware than the FitroDyne across the three exercises and seven loads. These findings further reinforce avoiding a reliance on measures of association as markers of agreement in method comparison studies whereby meaningful within-subject variation would likely be overlooked.

The strong correlations observed for peak velocity are similar to those found by Giroux et al. (14) (Force platform versus GymAware) and Orange et al. (20) (GymAware versus Push band) when comparing velocity for jump squat and back squat exercise, respectively. However, such statistics (i.e. measures of association) do not reflect absolute agreement between methods; more important is the observed random (within-subject) variation (19), which in the present study is large (coupled with systematic bias) across a range of exercise loads. For example, for bench press at 20% 1RM, the random error is too high (up to 37 $cm{\cdot}s^{-1}$) to identify the 10 $cm{\cdot}s^{-1}$ improvement reported by Turbanski and Schmidtbleicher (29) after 8-weeks of heavy (~80% 1RM) resistance training. Similarly, 60% 1RM for bench press revealed random errors more than twice that of the 4 $cm{\cdot}s^{-1}$ increase in peak barbell velocity observed with the addition of variable resistance (1). Therefore, the error between devices is greater than the improvements that are observed after resistance training interventions. As such, this indicates that peak velocity assessed via the FitroDyne and GymAware does not provide agreeable values across a range of loads.

Mean velocity was also well correlated between methods, and the absolute agreement was generally better than peak velocity, albeit the average velocity values were lower for mean than peak. Observations of good association and agreement in previous method comparison studies (indicated by strong correlations and small random errors, respectively) have been noted for mean velocity for squat and bench throw (GymAware versus 4 linear position transducers and force platform) (2,20). With respect to mean velocity, when adding a variable load (chains) to upper-body pushing exercise at 45 (15) and 60% 1RM (1) increases of 3 and 6 $cm \cdot s^{-1}$, respectively, have been documented. This cannot be measured suitably by both the FitroDyne and GymAware. Furthermore, an increase of 7 to 9 $cm \cdot s^{-1}$ in mean velocity, at loads of 30 to 100% 1RM, was associated with 5% increase in 1RM (16). The random errors observed in the present study challenge the ability of the FitroDyne and GymAware to monitor the changes observed by González-Badillo and Sánchez-Medina (16). In none of the aforementioned scenarios can the FitroDyne and GymAware be used interchangeably to detect such changes. For upper-body pulling-type exercise (bent-over-row), the authors are unaware of any existing data that examines increases in mean velocity after training interventions.

The generally poor levels of agreement between the methods reported here are undesirable from the perspective of using either device to detect meaningful changes in muscle function variables. Why the two do not agree satisfactorily might be explained by differences in the sampling method of each device. Whilst the FitroDyne employs a 100 Hz sampling method the GymAware uses a variable rate sampling method. The FitroDyne records displacement every 10 milliseconds (0.01 s). In contrast, under the variable rate sampling method, movement is recorded and time-stamped when there is a change of 600 microns (0.0006 m) after which the data are filtered to 50 samples per second. It is therefore plausible that the differences in sampling method have caused differences in velocity; notwithstanding the need for further investigation into specification differences. A further explanation could be due to differences in their cord tensions. The FitroDyne has a cord tension of less than 200 g, whereas that of the GymAware is four times greater (800 g). This would indicate a greater mass on the barbell side with the GymAware attached, causing a lower velocity. Although the Smith machine reduces deviations from parallel with the ground, there is likely to be some imbalance.

## PRACTICAL APPLICATIONS

The assessment of peak and mean velocity by the two commercially available rotary encoders is negatively affected by large random errors. In addition, meaningful systematic bias was observed for peak velocity with the FitroDyne providing higher values. These results were consistent across the three exercises and seven loads tested. This indicates that the FitroDyne and GymAware should not be used interchangeably, nor should their findings be compared. Whilst this might affect their use in applied and research settings, these devices can still provide a low cost and versatile method of assessing muscle function if they demonstrate acceptable reliability. Nevertheless, the researcher and applied practitioner must be cautious when comparing data using these measurement tools.

**Acknowledgements**

The authors would like to thank Ashley Armstrong and Christopher Quinn for their assistance with the data collection process. There are no conflicts of interest.

**Figure 1.** Mean (± D) values for peak and mean velocity during bench press, squat and bent-over-row. *denotes peak values are ·significantly different ($p < 0.05$). $^{x}$denotes mean values are significantly different ($p < 0.05$).

**Table 1.** Inter-repetition reliability (coefficient of variation) data for bench press, squat and bent-over-row.

**Table 2.** Method comparison statistics for bench press, squat and bent-over-row exercise

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**Table 1.** Inter-repetition reliability (coefficient of variation) data for bench press, squat and bent-over-row.

| | | | 20% 1RM | 30% 1RM | 40% 1RM | 50% 1RM | 60% 1RM | 70% 1RM | 80% 1RM |
|---|---|---|---|---|---|---|---|---|---|
| **Bench press** | Peak velocity | *FitroDyne* | 1.7 - 3.0% | 1.8 - 2.9% | 1.5 - 1.8% | 1.9 - 4.3% | 1.1 - 1.9% | 3.0 - 3.0% | 3.8 - 5.6% |
| | | *GymAware* | 1.6 - 2.6% | 1.1 - 1.7% | 1.1 - 1.6% | 1.8 - 3.4% | 1.3 - 2.2% | 2.9 - 6.1% | 3.8 - 5.2% |
| | Mean velocity | *FitroDyne* | 4.2 - 7.1% | 1.6 - 2.6% | 3.9 - 5.9% | 2.4 - 3.9% | 2.7 - 6.2% | 3.3 - 7.5% | 2.3 - 4.8% |
| | | *GymAware* | 2.9 - 4.7% | 1.2 - 2.0% | 2.3 - 2.8% | 1.4 - 2.1% | 1.4 - 2.0% | 2.2 - 6.3% | 2.9 - 4.9% |
| **Squat** | Peak velocity | *FitroDyne* | 3.7 - 5.0% | 4.1 - 5.9% | 2.3 - 3.9% | 2.4 - 3.1% | 2.1 - 3.0% | 2.1 - 4.0% | 3.7 - 4.0% |
| | | *GymAware* | 3.5 - 4.8% | 3.7 - 4.0% | 2.0 - 3.8% | 3.0 - 3.8% | 2.1 - 3.3% | 2.1 - 3.2% | 3.3 - 4.4% |
| | Mean velocity | *FitroDyne* | 3.0 - 3.9% | 1.6 - 4.4% | 1.7 - 4.0% | 2.0 - 2.9% | 2.3 - 4.2% | 3.1 - 3.8% | 2.3 - 9.0% |
| | | *GymAware* | 2.3 - 4.0% | 2.7 - 5.5% | 2.3 - 3.5% | 3.1 - 4.2% | 2.8 - 3.9% | 2.1 - 5.0% | 4.4 - 11.2% |
| **Bent-over-row** | Peak velocity | *FitroDyne* | 3.4 - 5.5% | 2.6 - 5.7% | 3.2 - 6.3% | 4.7 - 5.1% | 2.3 - 4.2% | 2.0 - 2.9% | 3.0 - 3.3% |
| | | *GymAware* | 2.3 - 4.8% | 3.3 - 5.8% | 3.9 - 6.7% | 2.1 - 4.3% | 4.8 - 5.4% | 1.6 - 3.3% | 3.3 - 3.7% |
| | Mean velocity | *FitroDyne* | 2.5 - 5.9% | 5.9 - 7.1% | 2.6 - 2.8% | 4.0 - 5.0% | 3.4 - 5.0% | 2.1 - 2.8% | 3.6 - 4.8% |
| | | *GymAware* | 3.1 - 5.3% | 4.2 - 5.2% | 3.7 - 6.0% | 4.9 - 5.6% | 2.6 - 3.8% | 2.4 - 2.6% | 2.4 - 5.5% |

**Table 2.** Method comparison statistics for bench press, squat and bent-over-row exercise

| **Load** (%1RM) | **Bench press** Peak velocity ($cms^{-1}$) | | Mean velocity ($cms^{-1}$) | | **Squat** Peak velocity ($cms^{-1}$) | | Mean velocity ($cms^{-1}$) | | **Bent-over-row** Peak velocity ($cms^{-1}$) | | Mean velocity ($cms^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *95% LoA* | *r* | *95% LoA* | *r* | *95% LoA* | *r* | *95% LoA* | *r* | *95% LoA* | *r* | *95% LoA* | *r* |
| 20 | 11.2 ± 25.9 | 0.86* | -4.8 ± 13.6 | 0.92* | 12.0 ± 8.8$^{+}$ | 1.00* | 2.0 ± 6.3 | 0.98* | 14.6 ± 25.0 | 0.94* | -0.1 ± 12.0 | 0.96* |
| 30 | 10.7 ± 22.9 | 0.79* | -2.0 ± 13.1 | 0.88* | 10.6 ± 9.3 | 0.99* | 0.6 ± 7.5 | 0.97* | 14.6 ± 18.9 | 0.93* | -0.8 ± 7.3 | 0.97* |
| 40 | 10.7 ± 12.1 | 0.92* | -0.9 ± 9.3 | 0.89* | 10.4 ± 9.1 | 0.99* | 1.2 ± 5.4 | 0.98* | 13.6 ± 12.0 | 0.97* | 0.4 ± 11.6 | 0.91* |
| 50 | 10.1 ± 4.5 | 0.98* | 0.1 ± 9.5 | 0.86* | 9.2 ± 7.4 | 0.99* | 2.3 ± 3.3 | 0.99* | 10.6 ± 6.8 | 0.98* | 0.6 ± 4.9 | 0.98* |
| 60 | 7.7 ± 3.8 | 0.99* | 0.0 ± 11.6 | 0.86* | 8.5 ± 5.8 | 1.00* | 2.0 ± 3.0 | 0.99* | 7.3 ± 18.2 | 0.92* | -0.3 ± 6.0 | 0.97* |
| 70 | 7.5 ± 9.6 | 0.95* | 0.2 ± 7.4 | 0.93* | 8.3 ± 5.4 | 1.00* | 2.2 ± 2.1 | 1.00* | 7.7 ± 15.3 | 0.91* | -0.2 ± 4.2 | 0.98* |
| 80 | 5.5 ± 10.1 | 0.96* | 1.0 ± 6.8 | 0.94* | 8.0 ± 6.5 | 1.00* | 1.1 ± 6.0 | 0.94* | 7.3 ± 14.9 | 0.92* | -0.2 ± 3.9 | 0.98* |

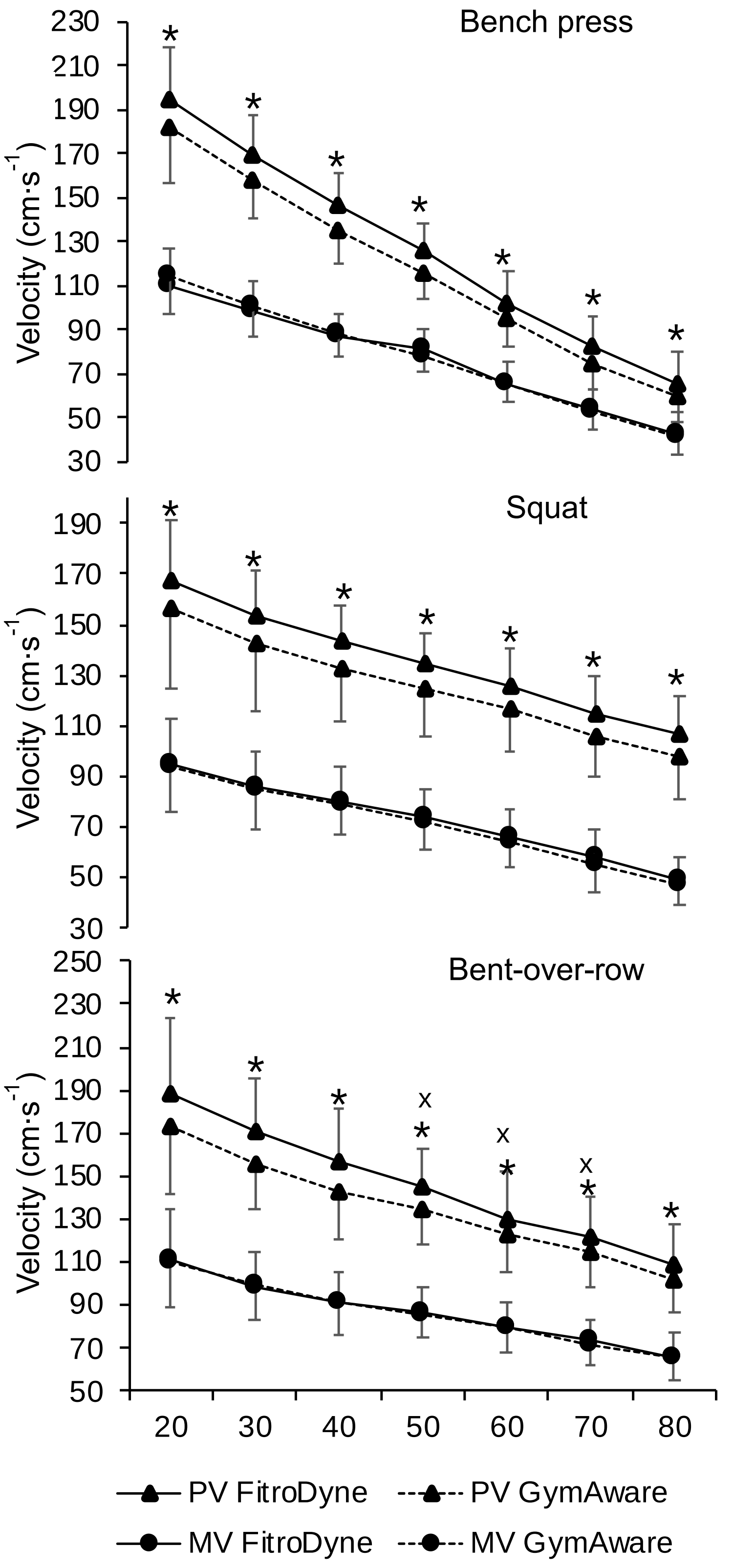


**Figure 1.** Mean (± D) values for peak and mean velocity during bench press, squat and bent-over-row. *denotes peak values are significantly different ($p < 0.05$). [x]denotes mean values are significantly different ($p < 0.05$).