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Original Article

Thera-band® elastic band tension: reference values for physical activity

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Abstract. [Purpose] The aim of this technical note was to report significant differences in the tension forces of the different-sized Thera-band® elastic bands (Hygenic Corp.) determined by us versus the manufacturer. [Subjects] Two trained observers performed all measurements. [Methods] The tension force (kilogram-force units) of eight color-coded elastic bands (tan, yellow, red, green, blue, black, silver, and gold) with different resistance levels was measured at 10 different percentages of elongation (25% to 250% with 25% increments) using an electronic elongation gauge tensiometer. [Results] There were significant differences in the tension force of the elastic bands of different colors when compared in pairs (excepting the tan/yellow pair) at 100% and 200% elongation, as determined via one-way analysis of variance. There were no differences in the slopes for the tan versus yellow and green versus blue bands, as determined via linear regression analysis and one-way analysis of variance. Comparison of the tension force values obtained in our study with the reference values of the manufacturer (the t-test applied to the slopes) showed significant differences for five colors (yellow, green, blue, silver, and gold). [Conclusion] Our results indicate that the tension force values for Thera-Band elastic bands provided by the manufacturer are overestimates.
Key words: Elastic band, Load monitoring, Physical exercise

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INTRODUCTION

Elastic bands (EBs) are simple-to-use tools for multipurpose physical training. They are portable, inexpensive, and widely used to develop muscle strength and power[1)]. They provide variable resistance similar to chains, cams, and levers, and their design allows changes in the external load over a range of motions. The EB deformation curve is associated with increasing strength and tension values; i.e., the more the band is stretched, the greater the resistance to further elongation. Thus, EB use is an easy way to increase exercise intensity while avoiding the risk of excessive weight loading. Because of their elasticity and ability to return to their original size, EBs can also be used to decrease the resistance load, making it easier to surpass exercise sticking points (e.g., in the bench press and squat)[1)].

The total volume or external load of resistance exercises is calculated as follows: total number of repetitions performed (sets × repetitions) × the load used for each exercise (kg)[2)]. It is difficult for health professionals involved in physical training, such as physiotherapists, physical educators, coaches, and personal trainers, to assess the exact load or tension of each EB exercise repetition because there is no visual indicator of tension and because the load changes as the extent of elongation of the EB changes (i.e., the total volume of the external load is not constant). An accurate estimation of the training load is of

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critical importance to athletes, patients, and the aforementioned health professionals, as it will improve exercise programs and minimize deleterious effects such as muscle and joint injuries.

Thera-Band® EBs are produced by the Hygenic Corp. (Akron, USA), the first major manufacturer and distributor of EB training products; many other companies that produce EBs have emerged recently[1]. The purpose of this study was to determine the tension of the different-colored Thera-Band EBs (color corresponds to the resistance level) at 10 percentages of elongation and to compare the values obtained with the reference values provided by the manufacturer.

SUBJECTS AND METHODS

We measured the tension force of Thera-Band EBs with different widths as distinguished by the following colors: tan, yellow, red, green, blue, black, silver, and gold. Samples of the EBs were prepared at 0.5-m lengths in the resting state, with one end of the EB fixed to a tensiometer (LUR-A-200NSA1; Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan) and the other end repeatedly stretched to predetermined levels according to the desired percentage of elongation. The resistance of the different colored EBs was measured at 10 elongations (25%, 50%, 75%, 100%, 125%, 150%, 175%, 200%, 225%, and 250%). The initial length was 0.3 m, and the maximum stretched length was 1.05 m. All measurements were performed by two trained observers, who visited the laboratory on two consecutive days. The room temperature varied from 22 °C to 24 °C, and the humidity was 50%. Each observer performed the same measurement five times, which resulted in a total of 10 samples per elongation percentage for each different-colored EB.

To accurately measure EB tension at the predetermined elongation percentages, we used a simple custom-built device consisting of an iron rail attached to a wooden platform. The rail had 10 consecutive marks (corresponding to the 10 elongation percentages listed above), which provided the precise locations for measurements along the horizontal axis. Rectangular metal blocks were fixed at the 10 marks along the rail and served as temporary attachment sites for the free end of the EB. The EB was anchored to an elongation gauge transducer tensiometer at the initial point on the device. Before the measurements were performed, the elongation gauge was calibrated by using standardized weights of 1 kg and 5 kg, and the results are presented in kilogram-force (kgf) units. The reference tension values provided by the manufacturer were converted from pounds to kgf to simplify comparisons. All statistical data analyses were conducted using JMP software version 11.2.0 (SAS Institute Inc., Cary, NC, USA) and an online statistical calculator[3]. The alpha level for significance was set at 0.05.

RESULTS

The tension force values (mean ± standard deviation) for the eight different-colored EBs at each percentage of elongation are presented in Table 1. The lowest values are in the top left corner and the highest values are in the bottom right corner, thus showing that tension force increases as the extent of elongation increases regardless of the color (resistance level) of the EB.

Table 2 presents the reference values provided by the manufacturer[4] for the different-colored EBs (excepting the tan

Table 1. Experimental measurement of the tension of the Thera-Band elastic bands of different colors at each elongation percentage (resting length = 0.3 m)

	Elongation percentage (m)									
	25% (0.38)	50% (0.45)	75% (0.53)	100% (0.60)	125% (0.68)	150% (0.75)	175% (0.83)	200% (0.90)	225% (0.98)	250% (1.05)
Tan	0.44 (0.03)	0.75 (0.04)	0.91 (0.03)	1.08 (0.01)	1.21 (0.06)	1.36 (0.05)	1.48 (0.07)	1.58 (0.04)	1.70 (0.05)	1.84 (0.07)
Yellow	0.48 (0.03)	0.83 (0.05)	1.04 (0.04)	1.17 (0.03)	1.26 (0.05)	1.41 (0.02)	1.55 (0.02)	1.69 (0.03)	1.83 (0.06)	1.98 (0.04)
Red	0.65 (0.02)	1.10 (0.03)	1.32 (0.05)	1.60 (0.05)	1.72 (0.08)	1.85 (0.02)	2.08 (0.02)	2.26 (0.04)	2.44 (0.10)	2.61 (0.05)
Green	0.78 (0.02)	1.24 (0.04)	1.56 (0.03)	1.82 (0.05)	2.15 (0.03)	2.35 (0.05)	2.64 (0.02)	2.91 (0.02)	3.23 (0.06)	3.65 (0.04)
Blue	1.15 (0.06)	1.70 (0.10)	2.14 (0.12)	2.51 (0.10)	2.85 (0.08)	3.09 (0.07)	3.32 (0.07)	3.52 (0.14)	3.85 (0.16)	3.98 (0.12)
Black	1.27 (0.03)	2.18 (0.06)	2.76 (0.04)	3.28 (0.05)	3.80 (0.04)	4.32 (0.05)	4.74 (0.06)	5.23 (0.12)	5.73 (0.05)	6.33 (0.10)
Silver	1.54 (0.04)	2.58 (0.03)	3.22 (0.04)	3.89 (0.07)	4.41 (0.09)	4.87 (0.10)	5.37 (0.10)	5.91 (0.07)	6.45 (0.14)	7.40 (0.10)
Gold	2.58 (0.06)	3.87 (0.03)	4.69 (0.09)	5.66 (0.06)	6.25 (0.20)	6.81 (0.18)	7.45 (0.25)	7.55 (0.21)	8.18 (0.34)	8.93 (0.21)

Values are expressed as the mean kilogram-force ± SD color) at the 10 elongation percentages (25% to 250%). All obtained experimental mean values were lower than their respective reference values, except for that of the yellow EB at 50% elongation, only 1% greater than the reference value (Table 3). The average differences between the experimental mean values and their corresponding reference values by color type were as follows: yellow, 15%; red, 13%; green, 18%; blue, 24%; black, 23%; silver, 36%; and gold, 44% (Table 3).

The experimental tension force values at 100% and 200% elongation for the eight tested EB resistance levels were compared by using one-way analysis of variance (ANOVA). The results showed a significant difference between the values for the different-colored EBs at both 100% elongation ($F_{7,72}$ = 6,459.77, p <0.0001) and 200% elongation ($F_{7,72}$ = 4,239.16, p <0.0001). Subsequent post hoc analysis using the Tukey-Kramer honestly significant difference (HSD) pairwise comparison and the Bonferroni correction for multiple comparisons showed differences in the tension values for all EBs paired by color (excepting tan/yellow pair) at both 100% and 200% elongation (Table 4), with progressively increasing tension force values, lowest at tan and highest at gold colored EB.

The linear regression equation was used to plot tension versus elongation, and the resultant mean slope values for the EBs of different colors were compared by using one-way ANOVA (Table 5). There was a significant difference between the values for the different-colored EBs ($F_{7,72}$ = 3,673.62, p <0.0001). Subsequent post hoc analysis (Tukey-Kramer HSD pairwise comparison with the Bonferroni correction) also showed significant differences in the values for all EBs paired by color, excepting the tan/yellow and green/blue pairs.

Lastly, we compared the linear regression slopes of the EB tension values obtained in this study (left side of Table 6) and the reference values (right side of Table 6). All linear regression equations had high coefficients of determination (r^2 >0.95). The mean slopes comparison showed greater values for reference for seven colors (yellow, red, green, blue, black, silver and gold), but statistical analysis using the t-test method described by Cohen et al.[5], found significant differences between the experimental and reference values for five colors (yellow, green, blue, silver, and gold).

DISCUSSION

When an elastic material is stretched, the amount of resistance in the material is proportional to the deformation of its initial length, as represented by a positive slope in a linear regression analysis. In other words, the greater the extent of elongation, the greater the generation of tension force. The mean tension force values obtained in our study, as well as the positive slopes in our linear regression analysis, confirm this relationship. Our values were less than those predicted by the

Table 2. Reference values for the tension of the Thera-Band elastic bands of different colors (adapted from reference 4)

	Elongation percentage									
	25%	50%	75%	100%	125%	150%	175%	200%	225%	250%
Tan	-	-	-	-	-	-	-	-	-	-
Yellow	0.50	0.82	1.09	1.32	1.54	1.77	1.95	2.18	2.40	2.63
Red	0.68	1.18	1.50	1.77	2.00	2.22	2.45	2.68	2.90	3.18
Green	0.91	1.45	1.91	2.27	2.59	2.95	3.27	3.58	3.99	4.35
Blue	1.27	2.09	2.68	3.22	3.67	4.13	4.58	5.03	5.49	6.03
Black	1.63	2.86	3.67	4.40	4.99	5.58	6.12	6.71	7.35	7.98
Silver	2.27	3.86	5.03	5.99	6.89	7.76	8.57	9.53	10.43	11.48
Gold	3.58	6.30	8.21	9.80	11.16	12.47	13.74	15.15	16.60	18.19

Data are expressed in kilogram-force units

Table 3. Differences between the mean experimental values and the reference values

	Elongation Percentage										
	25%	50%	75%	100%	125%	150%	175%	200%	225%	250%	Mean diff.
Yellow	4%	−1%	5%	11%	18%	20%	21%	22%	24%	25%	15%
Red	4%	7%	12%	10%	14%	17%	15%	16%	16%	18%	13%
Green	14%	14%	18%	20%	17%	20%	19%	19%	19%	16%	18%
Blue	9%	19%	20%	22%	22%	25%	28%	30%	30%	34%	24%
Black	22%	24%	25%	25%	24%	23%	23%	22%	22%	21%	23%
Silver	32%	33%	36%	35%	36%	37%	37%	38%	38%	36%	36%
Gold	28%	39%	43%	42%	44%	45%	46%	50%	51%	51%	44%

Differences in percentage = (1 − the experimental value ÷ the reference value) × 100 manufacturer for almost all of the eight different-colored bands tested. Applying the reference values when prescribing an exercise program would lead to an overestimation of the resistance or tension of the band, and in some circumstances, the difference could be more than twice the actual generated value (e.g., as seen for the gold EB elongated by 250%).

EB exercises for strength training have been reported to be less effective than exercises using free weights or weight-lifting machines[6], perhaps because of difficulties in controlling the intensity of the exerted strength with EBs. In fact, Andersen et al.[7] reported differences in the subjective efforts of perceived loading assessed according to the Borg Category Ratio (CR) 10 scale, which favored EB exercises compared with dumbbell exercises. These differences could be explained

Table 4. One-way analysis of variance comparing the tension values of the different colored Thera-Band elastic bands at 100% and 200% elongation

Elongation	Tan	Yellow	Red	Green	Blue	Black	Silver	Gold
100%*	1.08	1.17	1.60	1.82	2.51	3.28	3.89	5.66
	(0.01)	(0.04)	(0.05)	(0.05)	(0.10)	(0.06)	(0.08)	(0.02)
200%*	1.58	1.69	2.26	2.91	3.52	5.23	5.91	7.55
	(0.04)	(0.03)	(0.04)	(0.02)	(0.14)	(0.12)	(0.07)	(0.21)

Data are expressed as the mean kilogram force ± standard deviation. *significant difference by one-way ANOVA.

Elongation	Post Hoc tan/yellow		Post Hoc for the other colors*	
100%	Diff.	SED	Diff. Range*	SED
	0.09	0.03	0.22–4.58	0.03
200%	Diff	SED	Diff. Range*	SED
	0.11	0.05	0.58–5.97	0.05

*Post hoc Tukey Kramer honestly significant difference using the Bonferroni correction for multiple comparisons. SED: standard error of the difference; Diff.: difference

Table 5. One-way analysis of variance comparing the mean slope coefficients of the different colored Thera-Band elastic bands

	Tan	Yellow	Red*	Green	Blue	Black*	Silver*	Gold*
Mean Slope	0.579	0.608	0.807	1.192	1.216	2.124	2.373	2.607
	(0.021)	(0.017)	(0.018)	(0.010)	(0.055)	(0.025)	(0.044)	(0.088)

Values are reported as the mean ± standard deviation. *significant difference by one-way ANOVA.

Post Hoc tan/yellow		Post Hoc green/blue		Post Hoc for other pairs of colors*	
Diff.	SED	Diff	SED	Diff. Range	SED
0.029	0.019	0.023	0.019	0.199 – 2.028	0.019

*Post hoc Tukey Kramer honest significant difference using the Bonferroni correction for multiple comparisons. SED: standard error of the difference, Dif.: difference

Table 6. Thera-Band elastic band tension force linear regression equations comparison between experimental and reference data inference

	Experimental Data			Reference Data		
	Linear Regression	r^2	RMSE	Linear Regression	r^2	RMSE
Tan	$y = 0.44 + 0.579 \times \Delta$	0.969	0.08	-	-	-
Yellow*	$y = 0.49 + 0.608 \times \Delta$	0.971	0.08	$y = 0.36 + 0.918 \times \Delta$	0.997	0.04
Red	$y = 0.66 + 0.807 \times \Delta$	0.971	0.10	$y = 0.63 + 1.035 \times \Delta$	0.986	0.10
Green*	$y = 0.59 + 1.192 \times \Delta$	0.993	0.07	$y = 0.71 + 1.468 \times \Delta$	0.995	0.08
Blue*	$y = 1.14 + 1.216 \times \Delta$	0.958	0.18	$y = 1.05 + 2.012 \times \Delta$	0.993	0.14
Black	$y = 1.04 + 2.124 \times \Delta$	0.992	0.14	$y = 1.48 + 2.656 \times \Delta$	0.988	0.24
Silver*	$y = 1.29 + 2.380 \times \Delta$	0.987	0.20	$y = 1.85 + 3.878 \times \Delta$	0.993	0.26
Gold*	$y = 2.61 + 2.607 \times \Delta$	0.959	0.39	$y = 3.14 + 6.094 \times \Delta$	0.989	0.51

*Pairs of same color with significantly different slopes (t-test difference between slopes). Unit: kgf. RMSE (root mean square error).
y: predicted value for tension. **Δ:** elongation percentage ((final length − initial length) ÷ initial length)

by the overestimated tension values of the EBs. On the other hand, in the study by Colado & Tripplet[8], there were no differences in the effectiveness of EBs versus weight-lifting machines; however, the intensity of the load was determined by using a perceived exertion scale based on the maximum repetition test. Because these authors did not report the tension force or the amount of weight lifted, it is difficult to assume that the load or tension force of the EBs and the machines were equal. Assuming that the resistance level of the EB (color of EB) is a determinant factor (independent variable) for tension force, our results suggest that there is no significant difference in the tension levels of the tan and yellow bands, as determined by use of two different parameters for comparison (mean tension force and mean linear regression slope). Reference values for the tan EB were not available, but the results of the comparisons can be generalized for the yellow EB. Although the mean values for the slopes generated in our linear regression analysis for the blue and green EBs were considered statistically equal, different intercepts mean values for blue and green EB linear regression equations suggested parallel lines without coinciding points, thus indicating that the tension forces of these two colors of EBs were not equivalent. Lastly, paired comparisons of the slopes in the linear regression analysis of the experimental and reference data revealed no differences only at red and black colors. In contrast, the other EBs had overestimated slopes, which should compromise the accuracy of the load intensity in EB exercises and inflated the effectiveness of strength training.

A limitation of our study is the difficulty in comparing our results with those of previous studies because of the differences in the units used to measure force (usually newtons or pound force units). This difference could increase the error of variability owing to approximation of the values during their conversion. Nevertheless, the predicted values for the slopes of our experimental data were on average 31% and 36% lower than the those of Thomas et al.[9] and Hughes et al.[10], respectively. Sakanoue and Kitayama[11] also evaluated the tension of the different-colored Thera-band EBs. However, comparison of their results with ours is difficult, because they evaluated movements performed by the lower limbs, with elongation measured indirectly by variation of knee extension angles. Moreover, their experiment setting had the EB made into a 60-cm loop, theoretically generating the double the amount of tension for the same amount of elongation compared with our experimental design of simple stretching of a flat single-layer band. In contrast, in our study, the movements were performed by the upper limbs, with elongation directly measured at 10 different percentages, including measurements for all eight commercially available Thera band EBs.

Another limitation of our study is variations in the material caused by the temperature at the time of force measurement, which could partially explain the lower tension values in our results. However the optimal temperature of use of EBs was not noted in the manufacturer's manual or website, and our experimental conditions of temperature had only a small oscillation (22 to 24 °C). We assume that these conditions are similar to the ones found on the majority of rehabilitation/training facilities or at home. Therefore, we believe that our study appropriately estimates the tension values of Thera-band EBs in clinical practice.

Based on our findings, we recommend caution when using the reference values provided by the manufacturer to estimate the total volume and external load intensity of exercises performed with Thera-band EBs. Although the stratification of difficulty according to the color of the band is valid, the accuracy of the tension values must be tested in additional studies.

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