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Acute and Chronic Kinematic Effect of a Resistance Tubing Training Device on Youth Baseball and Softball Swings

Giordano KA[1], Wasserberger KW[1], Barfield JW[2] and Oliver GD[1]*

Abstract

Objective: Baseball and softball athletes often use swing training implements in preparation for an at bat, or to develop strength/power. The purpose of the present study is to examine the kinematic effects of a resistance tubing training device on youth baseball and softball swings both acutely, and after a 4-week intervention.

Methods: Twenty youth baseball and softball athletes participated. Ten completed the 4-week intervention and returned for follow up testing. Kinematic data were collected using an electromagnetic motion capture system on baseline swings. Participants then swung with the resistance tubing device, and then took it off, and subsequent swings were recorded. Participants completed a 4-week intervention using the swing trainer, and then reported back for follow-up testing. All collected swings were taken off a tee with the instructions to hit line drives up the middle of the cage. Data were analyzed for center of mass (COM) positioning over base of support (BOS), hand velocity, and hand path.

Results: Repeated measures analysis of variance revealed no significant changes in COM over BOS, hand velocity, or hand path between time points: baseline, acute, and follow-up.

Conclusion: The absence of significant kinematic changes means the resistance tubing swing training device could be used as a preparation tool for at-bats without the negative performance indicators reported in previous research on weighted implements.

Keywords

Athletics; Balance; Biomechanics; Intervention; Kinetic chain; Performance; Sport-specific

Introduction

Hitting performance in baseball and softball is reliant on the use of the entire body as a kinetic chain [1]. Given the importance of sequential timing in the kinetic chain and the correlation between balance and power production, pitchers often throw pitches of varying speeds in an attempt to disrupt a hitter's timing and balance [2,3]. To counter this, hitters often employ a number of strategies. Three such strategies are altering weight distribution for balance, to extending through the ball with the back elbow for optimal energy transfer and adapting hand path to the trajectory of the pitch to aid with timing. Specifically, regarding weight distribution, the technique of maintaining balance is to have a posterior weight shift to the back leg [4]. Considering back elbow extension, it is thought that extending the back elbow through ball contact will maximize the transition from rotational energy to translational energy of the bat head for a more effective force vector into the ball at contact. Additionally, keeping the hand path in the trajectory of the pitch will allow the bat to be in the hitting zone longer, and create a larger acceptable margin of error in timing while still contacting the ball [1]. Because a 90 mile per hour pitch take about 0.4 seconds to travel from the pitcher's hand to home plate, hitters must not only be efficient in segmental movements of the kinetic chain for optimal energy transfer [2,5-7], but also be efficient with the timing of the swing. The less time it takes the hitter to bring the bat to the point of ball contact, the more time the hitter has to adjust to varying speeds and locations of the pitch. Therefore, training that promotes balance, while controlling the center of mass (COM) towards the back foot over the base of support, an optimal hand path, and increased elbow extension at ball contact may prove beneficial to create a more efficient swing and aid hitting performance.

In attempt to improve hitting performance, many implements have been used in swing training including weighted bats, swing parachutes, and donuts [4,8,9]. One major purpose of these devices is to serve as an acute on-deck warm-up device prior to an at-bat. To prepare for an at-bat, a hitter must engage the neuromuscular system in movements similar to in-game mechanics to optimize swing velocity. There are mixed data as to whether weighted implements used prior to an at-bat help improve swing velocity, with some studies showing lighter or normal bat weights improve swing velocity compared to heavier bats [8], others showing no effect at all [9], and others showing no change in bat velocity, but a decreased response time to a change in stimulus velocity or location (simulated pitch) [10]. However, with psychology playing such a role in hitting performance, general consensus among coaches is that a hitter should warm up in a way which the hitter feels best prepares him or her to perform.

Swing training implements have also been used as a training intervention. When used as a training intervention, the goal is to improve lower extremity, lumbopelvic hip complex (LPHC) and torso rotational strength and power, which have been associated with increased swing velocity [11-17]. Hitters will use these implements at practice as a regimented protocol for tee drills, soft toss, batting practice, etc. Additionally, it is common for hitters to have a bat that is substantially heavier than the one they use in games to be used in practice in an effort to develop rotational power. This notion combines the concepts of resistance training with sport specific training. Because the nature of the baseball or softball swing is a unique and complex movement [1], training modalities that maximize transfer to sport performance are necessary to optimize carry over into swing velocity [1,7,14,18]. Using swing training aids allow hitters to apply overload and underload stimuli while maintaining high kinematic specificity.

While the majority of training devices previously discussed have consisted of some form of weight on the bat, increasing the force of gravity, the present study examined the use of a resistance tubing

***Corresponding author:** Gretchen D. Oliver, Sports Medicine and Movement Laboratory, School of Kinesiology, Auburn University, Auburn AL, USA, Tel: 859-200-4035; E-mail: goliver@auburn.edu

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swing trainer. Resistance tubing is a form of variable resistance training, which has been shown to increase power greater than that of traditional free weights alone [19-21]. In addition, variable resistance training has been shown to have a post-potentiation effect increase vertical jump height [22], a commonly used power measure. This could translate to similar beneficial effects in a baseball or softball swing. It could also be theorized that where using weighted implements will always increase the resistance vector with gravity, tubing resistance may be more effective at shifting the resistance vector closer to the line of the swing. This may promote the desired effects of keeping the weight back, a more efficient hand path and extending through the ball.

A recent study by Barfield and Oliver [23] examined a resistance tubing training device known as the Pitcher's Nightmare Swing Trainer and determined that there were no acute differences in COM location over base of support (BOS), or segmental velocities. However, if resistance tubing training can elicit acute changes in hand path or back elbow extension has yet to be determined. Additionally, the ability of a resistance tubing device to promote training adaptations in hand path, back elbow extension, and or COM positioning is unknown. Therefore, the purpose of this study was to examine acute and chronic kinematic changes in youth baseball and softball swings after a resistance tubing training intervention. We hypothesized that hand path would become more direct from hand initiation to ball contact both acutely and after a 4-week intervention; that there would be increased extension in the back elbow during the course of the swing both acutely and after a 4-week intervention; that COM positioning would be farther towards the back foot after a 4-week training intervention; and that hand velocity would be increased both acutely and after a 4-week intervention.

Methods

Experimental approach to the problem

All research was conducted in the Sports Medicine and Movement Laboratory within the School of Kinesiology at Auburn University. This was a longitudinal study with data recorded at baseline, acutely after swinging with a resistance tubing training device, and for follow-up after a 4-week intervention using the same device. Repeated measures analysis of variance (ANOVA) was used to observe center of mass (COM) over base of support (BOS), back elbow flexion angle, hand path from hand initiation to ball contact, and hand velocity at ball contact at baseline, immediately after swinging with the tubing device, and at follow-up after a 4-week intervention using the tubing device.

Participants

Twenty youth baseball and softball athletes (12.3 $\pm$ 2.1 yrs, 157.7 $\pm$ 13.6 cm, 51.6 $\pm$ 15.0 kg) were recruited, on a voluntary basis, to participate. Ten (11.6 $\pm$ 1.8 yrs, 150.4 $\pm$ 19.0 cm, 52.0 $\pm$ 13.6 kg) completed the 4-week intervention and returned for follow up testing. All participants in this study were currently an active participant on a competitive baseball or softball team, in good physical health, and had no injuries within the past six months. Auburn University's Institutional Review Board approved all testing protocols. Informed written consent and parental assent were obtained prior to testing.

Procedure

Participants reported to the lab without prior engagement in planned exercise on that day. Kinematic data were collected at 240 Hz using Flock of Birds electromagnetic tracking system (TrackSTARTMAscension Technologies Inc., Burlington, VT., USA) synced with The Motion Monitor (Innovative Sports Training, Chicago, IL., USA). Fourteen electromagnetic sensors were attached at the following locations: (1) the posterior/medial aspect of the torso at T1, (2) posterior/medial aspect of the pelvis at S1, (3-4) bilateral distal/posterior aspect of the upper arm, (5-6) bilateral at, broad portion of the acromion of the scapula, (7-8) bilateral distal/posterior aspect of the forearm, (9-10) bilateral distal/lateral aspect of the upper leg, (11-12) bilateral distal/lateral aspect of the lower leg, (13) dorsal aspect of the 3rd metatarsal of the lead leg and (14) dorsal aspect of the 3rd metacarpal of the top hand. Medial and lateral aspects of each joint were identified and digitized, with joint centers being calculated by the midpoint of the two points digitized.

The error in determining position and orientation of the electromagnetic sensors with the current calibrated world axis system was less than 0.01 m and 3°, respectively. Intra-rater reliability of digitization using the technique described below, which was determined during a pilot study of 5 active individuals, was an ICC (3, k) of 0.75 to 0.93 for all measurements. In order to ensure accurate identification and palpitation of bony landmarks, the participant stood in anatomical neutral throughout the duration of the digitization process so their body segments could be defined. Raw data regarding sensor position and orientation were transformed to locally based coordinate systems for each of the representative body segments. For the world axis, the positive Y-axis represented the vertical direction, in the direction of movement was the positive X-axis, and orthogonal to X and Y to the right was the positive Z-axis. Position and orientation of the body segments were obtained using Euler angle sequences that were consistent with the International Society of Biomechanics standards and joint conventions [24]. Elbow motion was captured as the forearm moving in reference to the arm in a Z, X', Y" Euler angle sequence, and all hand data were captured as the hand in reference to the world. COM was defined as the percentage of the body's COM position from the front leg to the back, with 0% indicating the body's COM positioned over the front leg and 100% indicating the body's COM positioned over the back leg [25].

The shoulder and hip joint centers were estimated using the rotation method, as has been shown to provide accurate positional data [26,27]. The shoulder joint center was calculated from the rotation of the humerus relative to the scapula, while the hip joint center was calculated from the rotation of the femur relative to the pelvis. The joint center variation in measurement had to have a root mean square error of less than 0.003 m to be accepted. A fourth-order Butterworth filter with a cutoff frequency of 13.4 Hz was used to smooth raw data of each digitized point [28,29].

Once the sensors were secured and the participant was digitized, the participant was allowed as much time as needed to warm up. Participants were told to hit line drives, up the middle of the cage, off of a tee until they were game ready. Tee positioning was left to participants' preference in order to hit line drives through the middle of the cage. Once completing the warm-up, participants took five swings attempting to hit hard line drives through the middle of the cage. After the five swings, participants were given three minutes of rest. Rest was implemented to ensure no carryover or fatigue from the previous swings. Following rest, participants were equipped with, and instructed, on the resistance tubing training device. Participants were then asked to perform 20 low efforts, dry swings with the resistance tubing device, in an effort to mimic being on-deck. After the 20 dry swings, participants were instructed to hit an additional five line-drives through the center of the cage while wearing the resistance tubing training device. Finally, the participant was asked to remove the device and hit five hard line drives up the middle. Following the collection, participants were instructed in an intervention using the resistance tubing swing trainer. The intervention consisted of 50 swings three days per week, for a total of 150 swings per week for 4weeks. The protocol of the swings for the intervention was all with the Pitcher's Nightmare Swing Trainer and can be found in Table 1. Data from the initial five hits prior to wearing the resistance tubing device (baseline) and the last five hits following the use of the resistance tubing device (acute resistance training) were used for analysis. Specifically, hits two through four of the baseline and acute resistance training hits were analyzed and chosen for analysis. Repetitions one and five were disregarded in order to avoid the Hawthorne effect.

Hitting was analyzed at five specific hitting events and across four phases. Event 1 was foot up, defined as the first frame visually observing the front foot off of the ground. Event 2 was foot contact, defined as observing a 50 N increase on the force plate when the front foot returned to the ground. Event 3 was hand initiation, defined by a change of .01 m in the positive X direction for hand position. Event 4 was ball contact, defined as the local maximum point of hand velocity at a reasonable position for ball contact. Event 5 was follow-through, defined as 25 frames after the point of ball contact. These five events divided the hitting motion into the four corresponding phases: Phase 1) between foot up and foot contact, Phase 2) between foot contact and hand initiation, Phase 3) between hand initiation and ball contact, and Phase 4) between ball contact and follow through. Additionally,

Table 1: Intervention Swing Protocol.

15 nice and easy dry* swings
10 step-across swings#
10 full speed dry* swings
15 swings off tee

*dry swing – no contact with a ball

#step-across swings - hitter begins positioned behind home plate, steps with the back leg towards home plate, then with the front leg into a hitting position, followed by a normal swing

COM over BOS was defined as a percentage of the body's COM from front to back over the BOS defined as distance between the front and back ankles and averaged across phases. Hand path was analyzed by breaking up Phase 3 (hand initiation to ball contact) into time normalized intervals of 10% with 0% marking hand initiation and 100% marking ball contact. Back elbow flexion was averaged across phases. Hand velocity was analyzed at the event of ball contact. A summary of events and phases can be found in Figure 1.

Statistical analyses

Repeated-measures analyses of variance were conducted to determine kinematic effects of the resistance tubing device at the time points of baseline, immediately following use, and for follow-up after a 4-week intervention. Bonferroni post-hoc analysis was used for any significant variables, and as an exploratory analysis for non-significant variables. Data were cleaned and formatted using MATLAB software, and analyzed using Statistical Package for Social Science (SPSS) software (version 25, SPSS Inc., Chicago, IL, USA) with an alpha level set *a priori* at $p \leq 0.05$.

Results

Repeated measures analyses of variance revealed no significance for kinematic variables COM over BOS or back elbow flexion at any phase during the swing, during the whole swing, or from foot contact to follow through both acutely and at follow-up (Tables 2 and 3); no significance for hand path changes in the x or y direction at any time-normalized point from hand initiation to ball contact both acutely and after follow-up (Figures 2 and 3, Tables 4 and 5); and no significant changes in hand velocity at ball contact ($F=0.119$, $p=0.888$) from baseline (1982.0 ± 206.1) to both acutely (2011.8 ± 204.7) and at follow-up (1996.1 ± 225.3) Tables 2-5 and Figures 2 and 3.

Discussion

This study aimed to build on a previous investigation by Barfield and colleagues [23] that determined this device could be used as an on-deck, warm-up device, as it would not actually change a hitter's swing. In addition to that investigation, this study examined acute effect on hand path and velocity, as well as effects on COM over

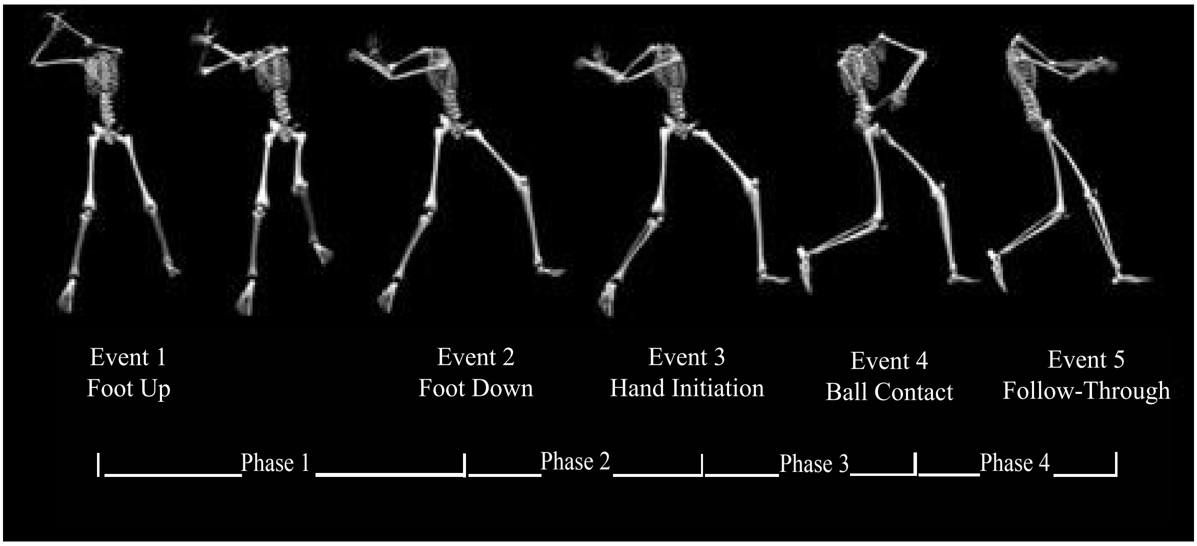

Figure 1: Swing events and phases.

Table 2: Elbow Flexion (degrees).

Time	Phase 1	Phase 2	Phase 3	Phase 4	Phases 1-4	Phases 2-4
Baseline	103.7 ± 50.1	100.5 ± 50.8	86.2 ± 50.0	35.7 ± 3	92.2 ± 45.5	72.3 ± 41.4
Acute	103.8 ± 49.3	102.4 ± 50.4	82.5 ±59.6	37.8 ± 29.2	92.2 ± 44.4	72.0 ± 40.8
Follow-up	111.0 ± 11.7	110.2 ± 9.9	101.1 ±10.3	49.7 ± 20.5	100.6 ± 12.4	82.9 ± 15.1
F, p	0.104, 0.902	0.153, 0.858	0.488, 0.617	0.717, 0.493	0.168, 0.846	0.332, 0.719

Table 3: COM over BOS (% front to back).

Time	Phase 1	Phase 2	Phase 3	Phase 4	Phases 1-4	Phases 2-4
Baseline	70.5 ± 28.2	57.1 ± 7.1	60.6 ± 9.0	63.6 ± 9.8	67.2 ± 20.6	60.5 ± 7.9
Acute	65.5 ± 13.9	56.4 ± 6.8	60.7 ± 8.4	64.4 ± 9.3	63.6 ± 9.8	60.6 ± 7.0
Follow-up	72.3 ± 12.8	61.1 ± 4.9	65.1 ± 6.1	68.7 ± 9.1	70.4 ± 8.3	65.4 ± 4.4
F, p	0.529, 0.592	1.827, 0.171	1.149, 0.325	1.170, 0.318	0.803, 0.453	2.085, 0.134

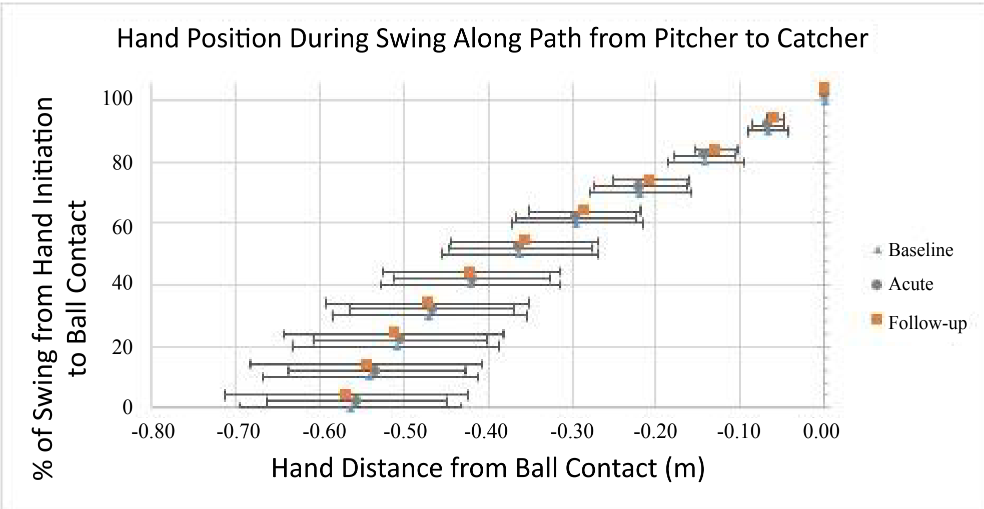

Figure 2: Hand position during swing along path from pitcher to catcher.

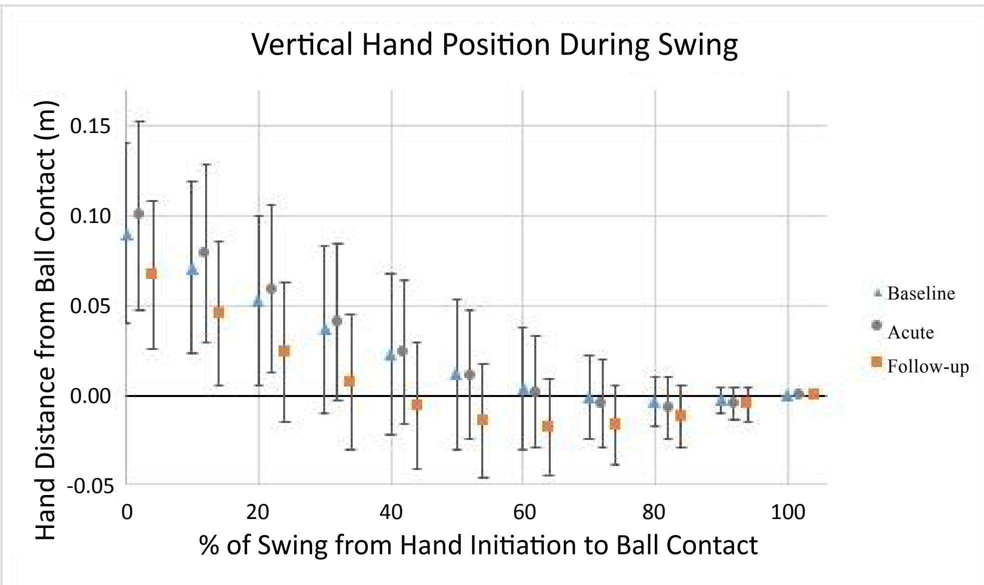

Figure 3: Vertical hand position during swing.

Table 4: Hand Position During Swing Along Path from Pitcher to Catcher.

	Time	Mean	Std. Deviation	*F*	*p*
X 0%	Baseline	-0.564	0.132	0.041	0.960
	Acute	-0.556	0.108		
	Follow-up	-0.568	0.144		
X 10%	Baseline	-0.540	0.128	0.032	0.969
	Acute	-0.533	0.105		
	Follow-up	-0.544	0.138		
X 20%	Baseline	-0.509	0.123	0.021	0.979
	Acute	-0.504	0.102		
	Follow-up	-0.512	0.130		
X 30%	Baseline	-0.470	0.116	0.009	0.991
	Acute	-0.466	0.098		
	Follow-up	-0.471	0.120		
X 40%	Baseline	-0.421	0.106	0.002	0.998
	Acute	-0.419	0.093		
	Follow-up	-0.419	0.106		
X 50%	Baseline	-0.362	0.093	0.016	0.984
	Acute	-0.362	0.085		
	Follow-up	-0.357	0.088		
X 60%	Baseline	-0.294	0.079	0.08	0.923
	Acute	-0.295	0.072		
	Follow-up	-0.284	0.067		
X 70%	Baseline	-0.219	0.061	0.226	0.798
	Acute	-0.220	0.055		
	Follow-up	-0.206	0.044		
X 80%	Baseline	-0.141	0.045	0.447	0.642
	Acute	-0.142	0.036		
	Follow-up	-0.129	0.024		
X 90%	Baseline	-0.066	0.024	0.654	0.524
	Acute	-0.067	0.019		
	Follow-up	-0.059	0.010		
X 100%	Baseline	0.000	0.000	.	.
	Acute	0.000	0.000		
	Follow-up	0.000	0.000		

BOS, hand path, and hand velocity over a 4-week intervention. Our hypothesis that hand path would be more direct to the ball both acutely and after 4-week intervention was not supported; our hypothesis that COM over BOS would be farther towards the back foot after a 4-week intervention was not supported; and our hypothesis that hand velocity at ball contact would be increased acutely and after a 4-week intervention was not supported. However, the absence of significant findings is not devoid of value.

The absence of significant changes means there were no negative training effects. Williams and colleagues [9] determined the best warm-up implement should be the device that the hitter feels the most comfort. It should be noted that though there were no significant changes, a portion of the youth in the current study responded favorably to the device and deemed it beneficial in their warm-up swings. Specifically, the participants noted that swinging with the resistance tubing made the bat feel lighter once the tubing was removed. This anecdotal participant feedback could allude to a psychological advantage. Combined with proper warm up and mental preparation, the resistance tubing training device could produce a psychological edge and confidence that a player should take to an at-bat, without the potential negative effects on bat velocity of weighted implements that some studies report [4,8]. Future research should analyze both the acute and training impact that a resistance tubing training device has on game performance.

Some participants also reported the lighter feeling of the bat made them feel improved control of the bat, which could be beneficial for quick adjustments to harder to hit pitches. While adding a wrist and forearm training protocol to a traditional lifting program did not increase performance measures in baseball swings [30], it could be theorized that the increased wrist strength is beneficial for bat control to optimize bat path through the hitting zone. While the present study did not find any changes in bat path from the resistance tubing intervention, it is worth noting the numerical trend of the bat path (Figure 3). The trend in bat path represents the vertical hand path after the intervention, which is lower and more curvilinear than baseline testing. Because of the line of pull of the tube from the back knee to the back elbow, this could be trending toward a training adaptation that creates more of an upper cut at ball contact. Further studies into performance are required to know whether or not this potential adaptation is advantageous. Also, future studies should control for the strength of the resistance tubing.

In addition, despite the decreased sample size completing follow-up testing, the standard deviation of back elbow flexion dramatically decreased, particularly up until ball contact from baseline and acute to follow-up (Table 2). This could be a constricting effect of the tubing

Table 5: Vertical Hand Position During Swing.

	Time	Mean	Std. Deviation	*F*	*p*
Y 0%	Baseline	0.090	0.050	1.565	0.218
	Acute	0.100	0.052		
	Follow-up	0.067	0.042		
Y 10%	Baseline	0.071	0.048	1.767	0.181
	Acute	0.079	0.050		
	Follow-up	0.045	0.040		
Y 20%	Baseline	0.053	0.047	2.045	0.139
	Acute	0.059	0.047		
	Follow-up	0.024	0.039		
Y 30%	Baseline	0.037	0.047	2.175	0.123
	Acute	0.040	0.043		
	Follow-up	0.007	0.038		
Y 40%	Baseline	0.023	0.045	2.129	0.129
	Acute	0.024	0.040		
	Follow-up	-0.006	0.035		
Y 50%	Baseline	0.012	0.042	2.017	0.143
	Acute	0.011	0.036		
	Follow-up	-0.015	0.032		
Y 60%	Baseline	0.004	0.034	1.851	0.167
	Acute	0.002	0.031		
	Follow-up	-0.018	0.027		
Y 70%	Baseline	-0.002	0.023	1.500	0.232
	Acute	-0.005	0.024		
	Follow-up	-0.017	0.022		
Y 80%	Baseline	-0.004	0.014	0.944	0.395
	Acute	-0.007	0.017		
	Follow-up	-0.012	0.017		
Y 90%	Baseline	-0.003	0.007	0.539	0.586
	Acute	-0.005	0.009		
	Follow-up	-0.005	0.009		
Y 100%	Baseline	0	0	.	.
	Acute	0	0		
	Follow-up	0	0		

device, where the elbow flexion angle did not significantly change, but it caused less deviation from the mean. Future research is needed to determine this device is narrowing in on, or away from an optimal elbow flexion angle.

It should be noted that the way COM over BOS was calculated makes it susceptible to variations during Phase 1. The calculation involved the position of the COM between the two ankles. Consequently, during Phase 1 when the front foot is off the ground, the COM position is dependent on how far back the athlete's front foot travels on their leg kick. Therefore, it is more appropriate to look at COM over BOS after foot contact, eliminating the load. For the whole swing without including Phase 1 (Table 3), there is a numerical difference, where the weight is shifted farther posteriorly, which may have reached significance with greater participant return for follow-up testing. Coaches teach keeping the weight back to help maintain balance, so there is "something left" to drive forward with. Therefore, if this tubing device does improve keeping the weight back, it could theoretically improve power via increased balance [3].

Although no significant changes were found neither acute nor after a 4-weeks intervention, there were numerical trends that started to form that could induce changes over a longer period of time, or that could show up with a greater sample size. Coaches, clinicians and strength and conditioning personnel should be aware of these trends because, while not statistically significant, they could indicate clinical meaning. Because of individual differences, some athletes may respond better to the potential changes seen in these trends, such as a greater upper cut towards ball contact, getting at the "launch angle" idea that is becoming more and more prevalent in baseball. With the known importance of a hitter warming up how they are comfortable [9], logic follows that if the hitter feels the induced changes are desirable, it would be reasonable to train in a similar manner. For warming up, the lack of significant changes can be interpreted as if the hitter feels comfortable using the resistance tubing device, it is an acceptable tool. For training in youth baseball and softball athletes, the resistance tubing device did not increase hand velocity at ball contact, which could be used as a performance indicator [31]; but because of individual differences in response to training, if an athlete is one who performs well with an increased upper cut at the ball, increased back elbow flexion, and a farther posteriorly shifted COM, then it could be used as a training device. To summarize, training devices and programs should be individualized to the athlete to achieve the desired outcomes.

This investigation is novel in that only few other studies have examined the use of resistance tubing on baseball or softball swings [4,23], and that this study examines altering the line of resistance in training devices which could help train individuals to gain an edge in the "launch angle revolution." We did not find evidence of changes in swing kinematics neither acutely, nor after a 4-week intervention; however, there limitations that should be noted. Because of the age of the population, adherence to the protocol is always a factor, as well as participants dropping out. With limited size and a convenience sample, results may not translate to the entirety of youth baseball and softball populations. Also, to be considered are the number of swings taken daily and weekly by the population of interest. With resistance tubing applied to the body, the body behaves by the specific adaptations to imposed demands principle. Not taking the influence of number of swings normally swung during the week serves as a limitation and a direction for future studies because that will aid in establishing the degree and intensity of a training program. Baseball and softball athletes were also included an analyzed as the same population. Because of the setting, it is difficult to mimic in game swings in a laboratory, and with a tee [32]. Last, we assume that bat velocity correlates with hand velocity, but we did not directly measure bat velocity as a performance outcome. Future studies should examine the effect that the amount of resistance felt in a resistance tubing training device has on a baseball or softball swing. Also, a longer intervention with a larger sample size should be conducted to either confirm or contradict the results found in this study. Future studies should also look at swing kinematics and changes with soft toss or simulated games.

Conclusion

Resistance tubing training devices were not shown to change acute swing kinematics, or after a 4-week intervention. Since there were no detrimental effects, it can be used as a warmup, on-deck device; however, for training, it should only be used if observed individual changes are favorable for that specific athlete.

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Author Affiliation Top

[1]Sports Medicine and Movement Laboratory, School of Kinesiology, Auburn University, Auburn AL, USA

[2]Physical Education & Exercise Science Department, Lander University, Greenwood, SC, USA