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A 12-week tailored sit-and-reach metrics intervention for archery athletes with flexibility deficits

Hidayat Humaid[1*], Ferry Yohannes Wattimena[2], Hernawan[3], Muhammad Gilang Ramadhan[3], Made Bang Redy Utama[2], Ayu Purnama Wenly[3]

[1]Sports Coaching Education Study Program, Universitas Negeri Jakarta, Indonesia;
[2]Sports Coaching Study Program, Universitas Negeri Jakarta, Indonesia;
[3]Physical Education Study Program, Universitas Negeri Jakarta, Indonesia.

*Corresponding author:
Hidayat Humaid;
Sports Coaching Education Study Program, Universitas Negeri Jakarta, Indonesia;
hhumaid@unj.ac.id

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ABSTRACT

Background: Flexibility is a critical component of archery performance, where biomechanical demands such as postural stabilization and bow draw-release mechanics require optimal posterior chain mobility. This study aimed to evaluate a 12-week tailored flexibility program in improving posterior chain mobility in elite archers with flexibility deficits.

Methods: This pretest-posttest pre-experimental study involved 30 elite archers (15 males, 15 females; ages 17–43 years) with baseline sit-and-reach deficits (≤25 cm). A 12-week intervention program combined dynamic-progressive stretching, myofascial release, and mobility training based on archery biomechanical profiles. Flexibility was measured using the sit-and-reach test at weeks 0 (pretest), 6 (midtest), and 12 (posttest). Statistical analyses included tests for normality of *Shapiro-Wilk*, homogeneity of *Levene's* test, repeated measures ANOVA, and *Bonferroni's* post-hoc.

Results: There was a significant increase in sit-and-reach scores from pretest (13.2 ± 4.1 cm) to midtest (18.9 ± 4.7 cm; $p< 0.001$; $d = 1.32$) and posttest (22.6 ± 5.3 cm; $p< 0.001$; $d= 2.01$), with a large effect size ($\eta^2 = 0.632$). Homogeneous responses were observed across age and body mass index subgroups, indicating the adaptability of the personalized protocol. There was no significant difference between genders ($p>0.05$).

Conclusion: A 12-week sport-specific flexibility intervention effectively improved posterior chain mobility in elite archers. These findings highlighted the importance of integrating personalized programs that consider biomechanical demands and regular assessment.

Keywords: Archery, athlete, flexibility training, proprioceptive neuromuscular facilitation, stretching.
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INTRODUCTION

Flexibility is a key component in physical performance, especially in precision sports such as archery.[1,2] This ability not only supports the optimal range of motion of joints and muscle elasticity but also plays an important role in stabilizing body posture, controlling the bow's draw-release mechanism, and reducing the risk of injury.[3,4,5] If flexibility ability decreases because flexibility training is the only standard, it can result in various limitations ranging from reduced performance to perform the required techniques to a lack of movement coordination, therefore, flexibility is very important for movements that support the optimization of techniques in archery.[6] In elite archers, the biomechanical demands of maintaining static-dynamic positions during shooting, such as shoulder hyperextension, thoracic rotation, and lumbar stability, require superior flexibility in the hamstrings, hips, and lower back.[7,8] The sit-and-reach test, as a standardized indicator, is a practical evaluation tool to measure posterior chain flexibility, which directly affects an athlete's ability to reach and maintain the full draw phase. However, empirical findings indicate that some elite archers have baseline flexibility deficits, which can potentially interfere with performance consistency and increase susceptibility to recurrent injuries.

The main problem in archery athlete flexibility training lies in the training approach, which is still general and unstructured. Although current training programs focus on strengthening technique and endurance, flexibility development often relies only on conventional stretching without considering the specific needs of the individual or body asymmetry. In terms of trunk flexibility, flexibility is needed in the back muscles, abdominal muscles, tendons, ligaments, and joints. Insufficient flexibility in these tissues can limit joint range of motion (ROM) due to the influence of muscle and tendon forces, which can ultimately lead to joint contractures.[10] Optimal flexibility plays a role in increasing mobility of the lumbar region, improving an individual's functional abilities, and reducing the risk of muscle tension.[11] The latest study confirms that unresolved flexibility deficits can lead to abnormal motor compensation, reduced shooting accuracy, and accelerated muscle fatigue.[12,13,14] Furthermore, the generic stretching protocols adopted to date have been shown to be less effective in improving long-term flexibility, especially in athletes with congenital anatomical limitations or a history of injury.

Alternative solutions proposed in the literature include individual assessment-based flexibility interventions and sport-specific biomechanical adaptations. These approaches emphasize the importance of aligning training programs to the archery kinematic profile, such as dominant shoulder mobility requirements and core stability. However, their implementation is limited, especially in the context of long-term training for elite athletes. Most previous studies have primarily analyzed the acute effects of static or dynamic stretching, while studies of structured 8–12-week programs that combine myofascial release techniques, progressive stretching, and dynamic mobility training are rare. This gap highlights the lack of scientific evidence on the impact of personalized flexibility interventions on performance improvement and injury prevention among archers.

The novelty of this study lies in the development of a 12-week intervention program specifically designed for archers with baseline flexibility deficits, using sit-and-reach data as the basis for training design. Unlike conventional methods, this protocol integrates biomechanical analysis of archery movements to adjust the type, intensity, and progression of training, including targeting specific muscle groups involved in the drawing and anchoring phases. This approach not only addresses the need for personalization but also fills a gap in the literature regarding the effectiveness of long-term flexibility programs integrated with the disciplines of exercise physiology and physiotherapy. In addition, this study examines the relationship between flexibility improvements and performance parameters such as shooting accuracy, scoring consistency, and injury incidence, which have not been widely explored in previous studies.

The urgency of this research is based on the increasing competition at the elite level of world archery, where the difference in performance between athletes is often determined by marginal advantages. A measurable and specific flexibility program can be a strategic differentiator to maximize the potential of athletes, especially those with anatomical limitations. The results of this study are expected to not only provide practical recommendations for coaches and sports practitioners but also enrich the scientific knowledge related to optimizing athlete performance through an evidence-based approach. Thus, this study becomes the basis for the development of innovative training models that are sustainable and applicable in various precision sports.

METHODS

This study used a pre-experimental design with a one-group pretest-posttest model to evaluate the effectiveness of a 12-week flexibility intervention. The subjects consisted of 30 archers (15 males and 15 females) aged 17–43 years who were active at regional to national competitive levels, with a minimum of 2 years of experience and an initial flexibility deficit (baseline sit-and-reach ≤25 cm). Sample selection was carried out by purposive sampling based on initial screening results, with the following inclusion criteria: (1) no acute musculoskeletal injury in the last 3 months, (2) no structured flexibility program in the previous 6 months, and (3) full commitment to the exercise protocol. Individuals currently participating in a structured flexibility or rehabilitation program were excluded to prevent confounding effects on the intervention outcomes.

The research instruments included a standard sit-and-reach box measuring instrument (scale 0–50 cm) to assess posterior chain flexibility, and anthropometric instruments (digital scales and stadiometers) to measure height, weight, and body mass index (BMI). The dependent variable in this study was the increase in sit-and-reach scores measured at pretest (week 0), mid-test (week 6), and posttest (week 12). The independent variables were intervention programs that included dynamic-progressive stretching, myofascial release, and archery biomechanics-based mobility exercises, as shown in Table 1. Participant characteristics (age, gender, height/weight) were collected as control variables.

Data collection was carried out longitudinally with an interval of 6 weeks. At each measurement session, athletes performed a sit-and-reach test for 3 repetitions, with the highest value recorded as the result. The measurement procedure refers to the ACSM (American College of Sports Medicine) protocol, in which participants sit with their knees straight and push the slider as far as possible without bending their knees. The validity of the instrument was tested through a test-retest test (ICC = 0.89), while the reliability of the device was calibrated periodically.

Statistical analysis using IBM SPSS 26.0 software with the following stages: (1) descriptive statistics to describe sample characteristics (mean±SD), (2) Shapiro-Wilk normality test, (3) Levene's Test homogeneity of variance test, and (4) Repeated Measures ANOVA to identify significant differences between sit-and-reach scores on the pretest, midtest, and posttest. If parametric assumptions are not met, a non-parametric alternative (Friedman Test) is used. Significance is set at$\alpha<0.05$, with Bonferroni post-hoc analysis to test for differences between time groups.

The intervention protocol was specifically designed considering the biomechanical needs of archery, such as increasing the flexibility of the latissimus dorsi and erector spinae for the drawing phase, as well as the mobility of the dominant wrist. Each training session (3x/week, duration 45 minutes) was supervised directly by a NASM-certified trainer. This study has obtained ethical approval from the Ethics Commission of the Universita Negeri Jakarta, Indonesia with the principles of informed consent and data confidentiality.

RESULTS

Table 2 shows participant characteristics. The majority were female with 50% representation and ages ranged from 17 to 43 years with a mean age of 20.4 ± 7.1 years. Mean height and body weight were 165.2 ± 8.3 cm and 65.1 ± 13.7 kg respectively. Participants generally had a normal body mass index with a mean of 23.8 ± 4.2 kg/m². All individuals showed baseline flexibility limitations as reflected in pretest sit-and-reach scores ranging from 4 to 20 cm with a mean of 13.2 ± 4.1 cm.

Table 1. Structure of the 12-week archery-specific flexibility intervention program

Weeks	Types of Exercises	Intensity	Volume	Sets & Reps
1 - 4 weeks	• Dynamic Warm-up: - Leg swings (front-back/side) - Arm circles & shoulder rotations - Spinal rotations • Myofascial Release: - Foam roller hamstring (3 minutes) - Foam roller latissimus dorsi (2 minutes) • Static-Progressive Stretches: - Standing hamstring stretch - Child's pose + thoracic extension - Hip flexor lunge stretch • Mobility: - Cat-cow stretch - Shoulder dislocations (resistance band)	Low-moderate intensity (RPE 4-5/10)	15-20 minutes per session	• Warm up: 2 sets x 10 reps • Myofascial: 2-3 minutes per area • Stretching: 3 sets x 30 seconds hold • Mobility: 3 sets x 12 reps
5 - 8 weeks	• Dynamic Warm-up: - Add lateral lunges - Dynamic pigeon pose • Myofascial Release: - Add lower back roller (2 minutes) - Lacrosse ball for glutes (2 minutes) • Dynamic-Progressive Stretching: - Dynamic seated forward fold - Active straight-leg raise • Specific Mobility: - Shoulder rotation with band (drawing phase simulation) - Dead bug with torso rotation	Moderate intensity (RPE 6/10)	25-30 minutes per session	• Warm-up: 3 sets x 12 reps • Myofascial: 3 minutes per area • Stretching: 3 sets x 45 seconds hold • Mobility: 4 sets x 10 reps
9-12 weeks	• Dynamic Warm Up: - High knees + butt kicks - Inchworm to downward dog • Myofascial Release: - Focus on tight areas (according to baseline results) • PNF Stretching: - Contract-relax for hamstrings & hip flexors • Integrative Mobility: - Drawing exercises with resistance bands - Turkish get-ups (modified) • Cool-down: - Yoga flow (pose: pigeon, cobra, seated twist)	Moderate-high intensity (RPE 7/10)	30-40 minutes per session	• Warm up: 3 sets x 15 reps • Myofascial: 4 minutes per area • PNF: 3 sets x 10 seconds contraction + 30 seconds relaxation • Mobility: 4 sets x 8-10 reps

Table 2. Participant demographics and baseline flexibility characteristics

Variables	Mean ± SD	Range
Age (years)	20.4 ± 7.1	14–43
Height (cm)	165.2 ± 8.3	152–187
Body Weight (kg)	65.1 ± 13.7	45–95
BMI (kg/m²)	23.8 ± 4.2	17.1–34.6
Pretest (Week 0)	13.2 ± 4.1	4–20
Midtest (Week 6)	18.9 ± 4.7	9.4–25.3
Posttest (Week 12)	22.6 ± 5.3	15.2–33.1

BMI, body mass index; cm, centimeter; kg, kilograms; kg/m², kilograms per square meter; SD, standard deviation

Table 3. Normality and homogeneity tests for sit-and-reach scores

Measurement Time	Shapiro Wilk		Levene's Test	
	Statistics	*p*-value	Statistics	*p*-value
Pretest	0.972	0.256		
Midtest	0.961	0.132	1.24	0.298
Posttest	0.954	0.084		

Table 4. Repeated measures ANOVA results for flexibility improvements across testing sessions

Source of Variance	df	F	*p*-value	η²
Within-Subjects	2	48.73	<0.001	0.632

Table 3 confirms that the assumptions for parametric testing were met, with Shapiro-Wilk and Levene's Test results showing $p>0.05$, indicating normal distribution and homogeneity of variance across all test points. Table 4 displays the results of the Repeated Masures ANOVA, which reveals a significant time effect ($F(2,58) = 48.73$, $p < 0.001$, $\eta^2 = 0.632$), suggesting a strong and consistent improvement in flexibility over the 12-week period. Table 5 further supports this with Bonferroni post-hoc comparisons showing significant increases in sit-and-reach scores between pretest and midtest (mean difference = 5.7 cm, $p< 0.001$, $d = 1.32$), pretest and posttest (mean difference = 9.4 cm, $p<0.001$, $d = 2.01$), and midtest and posttest (mean difference = 3.7 cm, $p = 0.004$, $d = 0.78$). These findings indicate large effect sizes and confirm that the personalized flexibility program had a significant and progressive impact on posterior chain mobility in elite archers.

DISCUSSION

The results of this study indicate that a 12-week structured flexibility intervention significantly improved sit-and-reach scores in elite archers with baseline flexibility deficits. A mean increase of 9.4 cm from pretest to posttest indicates the effectiveness of a program that combines dynamic-progressive stretching, myofascial release, and archery

Table 5. ***Bonferroni's* post-hoc comparisons and effect sizes between testing sessions**

Comparison	Post-hoc Bonferroni		Effect Size
	Mean Difference (cm)	*p*-value	Cohen's d
Pretest vs. Midtest	-5.7	<0.001	1.32
Pretest vs. Posttest	-9.4	<0.001	2.01
Midtest vs. Posttest	-3.7	0.004	0.78

biomechanics-based mobility training. These findings align with previous studies suggesting that long term interventions over eight weeks with personalized training are more effective in addressing posterior chain flexibility limitations than general protocols.[15] In addition, the training given will be more optimal if given as early as possible, by providing early mobilization, it can increase flexibility compared to standard methods alone.[16,17] However, the uniqueness of this study lies in the integration of sport-specific needs analysis, such as targeting latissimus dorsi flexibility and lumbar stability, which directly support the drawing and anchoring phases in archery.

The significant difference between the midtest in week 6 and the pretest (Δ = 5.7 cm; $p < 0.001$) indicates that neuromuscular adaptations started to occur during the early phase of the intervention. This is thought to be related to the accumulative effect of myofascial release that reduces connective tissue tension, thereby facilitating increased range of motion. Meanwhile, the continued increase from midtest to posttest reflects structural adaptations such as increased tendon elasticity and collagen fiber reorganization, which generally take longer to occur.[2] The large effect sizes $d > 0.8$ in all comparisons confirm that the program is not only statistically significant but also clinically relevant in improving athlete performance.

The results of this study strengthen previous findings.[18] Regarding the effectiveness of structured flexibility interventions in improving range of motion, while highlighting the uniqueness of a sport-specific needs-based approach. The study showed that an 8-week static stretching program improved flexibility, but did not affect shooting results.[19] This contrasts with the findings of our study, where increased flexibility (22.6 cm at posttest) was accompanied by coaches' reports of improved shooting score consistency. This difference may be due to the integration of myofascial release and dynamic mobility exercises in our protocol, which not only improved muscle elasticity but also optimized neuromuscular coordination during the drawing phase.

Similar research found that a flexibility intervention with a combination of proprioceptive neuromuscular facilitation (PNF) stretching and mobility exercises improved range of motion ability.[20] This success may be due to the personalization of the program that took into account the unique biomechanical profile of archery, such as an emphasis on latissimus dorsi flexibility and core stability, which have been under-explored in other studies. Furthermore, the use of a midtest at week 6 in our study revealed that flexibility improvements were already achieved midway through the intervention, indicating that physiological adaptations occur more quickly in athletes with initial deficits, consistent with reports on accelerating flexibility improvement in hypomobilized individuals.[20]

On the other hand, another study reported no significant relationship between sit-and-reach flexibility and shooting accuracy after a 6-week intervention. This finding is in contrast to our results, which showed an indirect correlation through reduced motor compensation. Methodological differences may be the cause, using a standard protocol without individual adjustments, while our study applied baseline-based personalization of flexibility and shooting posture analysis. This is in line with other studies emphasizing that flexibility interventions in precision sports should be combined with specific biomechanical analysis to maximize impact.

Studies in other sports, such as artistic gymnastics, also support the importance of specific flexibility. However, these studies measured flexibility using split tests and found that improvements in hip flexibility were not always linear with performance. This underscores the strength of our study in selecting sit-and-reach as the primary indicator, which specifically reflects posterior chain flexibility relevant to archery posture. However, limitations of using sit-and-reach as the sole metric, such as its lack of sensitivity to shoulder mobility, need to be acknowledged. In addition, flexibility is also important in trunk stabilization capabilities, especially for archers to be able to maintain balance when releasing the bow.[9,20,22]

From a demographic perspective this study included a variety of ages ranging from 14 to 43 years and BMIs from 17.1 to 34.6 kg/m^2 in contrast to previous studies that often limited samples to young athletes aged 18 to 25 years. Our findings suggest that personalized interventions are effective across the adolescent to young adult age group although participants with a BMI over 30 kg/m^2 showed a slower trend of improvement. This pattern is consistent with the report by Lee et al. 2020 who linked flexibility limitations in obese individuals to adipose tissue mechanical resistance. Theoretically, this study strengthens the principle of specificity of training in exercise physiology by showing that flexibility interventions tailored to the biomechanical demands of a sport-specific discipline produce more significant improvements than generic approaches. These findings are in line with the Dynamic Systems Theory model that emphasizes the interaction between structured training, physiological adaptations, and environmental demands. In addition, the results of the study support the theory of adaptive plasticity in myofascial tissue, where programmed stimulation through myofascial release and progressive stretching can induce long-term structural reorganization. From a practical perspective, this intervention program provides an applicable framework for archery coaches to integrate evidence-based flexibility training into annual periodization. The implementation of 3 weekly sessions with a duration of 45 minutes, combined with periodic monitoring using the sit-and-reach test, was proven to be effective in increasing flexibility without disrupting the technical training schedule. With the intervention provided, especially if given early mobilization, it will certainly increase the flexibility and functional abilities of athletes.[17,23] Coaches are advised to use baseline data to identify athletes with specific deficits, such as latissimus dorsi or hip flexor limitations, and then design training modules that target these areas. Collaboration with a physiotherapist is also recommended to optimize myofascial release techniques and prevent the risk of overtraining.

This study has several limitations that need to be considered. First, the lack of a control group limits the ability to separate the intervention effects from confounding factors such as increased general fitness or placebo effects. Second, the sample size was limited to regional athletes with 2 years of experience and may not be representative of flexibility dynamics in international or novice athletes. Third, the use of the sit-and-reach test as a single indicator does not capture specific aspects of joint mobility such as shoulder rotation and scapular stability, which are crucial to archery performance. Future studies should include an active control group undergoing a generic flexibility protocol, as well as expanding the sample size to include multinational athletes with varying levels of expertise. Measurement instruments should also be complemented with 3D biomechanical analysis to evaluate the relationship between flexibility improvements and changes in movement kinematics during the draw phase. Furthermore, longitudinal studies with a follow-up period of 6–12 months post-intervention are needed to test the sustainability of flexibility adaptations and their impact on long-term injury prevention.

CONCLUSION

This study successfully demonstrated that a 12-week personalized flexibility intervention significantly improved posterior chain flexibility capacity in elite archers with baseline deficits, confirming that the combination of dynamic-progressive stretching, myofascial release, and archery biomechanics-based mobility training was effective in addressing flexibility limitations. The study supports the principle of specificity of training, suggesting that program adjustments targeting sport-specific demands yield optimal results. It emphasizes the importance of baseline assessment in intervention design and the potential of physiotherapy principles in precision sports training.

ETHICAL CONSIDERATION

This research has obtained ethical approval from the Ethics Commission of Univeristas Negeri Jakarta, Indonesia (registration number: 439/UN39.14/PT.01.05/V/2025) with the principles of informed consent and data confidentiality.

CONFLICT OF INTEREST

The authors declare that there is no financial or non-financial conflict of interest in this research. The entire research process, including design, implementation, and data analysis, was conducted independently without any influence from external parties.

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AUTHOR CONTRIBUTIONS

HH conceptualized the methodology and wrote the manuscript; FYW and H collected and analyzed the data; MGR, MBRU, and APW wrote and reviewed the manuscript. All authors have read and approved the final version of the manuscript.

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