

22 **ABSTRACT**

23 **Background:** The epidemiology and aetiology of hamstring injuries in sport have
24 been well documented. Kinesiology tape has been advocated as a means of
25 improving muscle flexibility, with potential implications for injury prevention.

26 **Purpose:** To compare the temporal pattern of efficacy of kinesiology tape and
27 traditional stretching techniques on hamstring extensibility. **Study Design:**

28 Controlled laboratory study. **Methods:** Thirty recreationally active male participants
29 (Mean \pm SD: age 21.0 ± 0.1 years; height 180 ± 6 cm; mass 79.4 ± 6.9 kg)

30 completed an active knee extension assessment (of the dominant leg) as a measure
31 of hamstring extensibility. Three experimental interventions of equal time duration
32 were applied in randomized order: Kinesiology tape (KT), static stretch (SS),

33 proprioceptive neuromuscular facilitation (PNF). Measures were taken at baseline,
34 +1, +10 and +30 mins after each intervention. The temporal pattern of change in

35 active knee extension was modelled as a range of regression polynomials for each
36 intervention, quantified as the regression coefficient. **Results:** With baseline scores

37 not statistically different between groups, and baseline AKE set at 100%, PNF

38 showed a significant improvement immediately post-intervention (PNF₊₁ = $107.7 \pm$

39 8.2% , $p = .01$). Thereafter, only KT showed significant improvements in active knee

40 extension (KT₊₁₀ = $106.0 \pm 7.1\%$, $p = .05$; KT₊₃₀ = $106.9 \pm 5.0\%$, $p = .02$). The

41 temporal pattern of changes in active knee extension after intervention was best

42 modelled as a positive quadratic for KT, with a predicted peak of 108.8% baseline

43 score achieved at 24.2 mins. SS was best modelled as a negative linear function,

44 and PNF as a negative logarithmic function, reflecting a rapid decrease in active

45 knee extension after an immediate positive effect. **Conclusion:** Each intervention

46 displayed a unique temporal pattern of changes in active knee extension. PNF was

47 best suited to affect immediate improvements in hamstring extensibility, whereas
48 kinesiology tape offered advantages over a longer duration. **Clinical Relevance:**
49 The logistics of the sporting or clinical context will often dictate the delay between
50 intervention and performance. Our findings have implications for the timing and
51 choice of intervention aimed at increasing hamstring extensibility in relation to
52 performance.

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54 **Level of Evidence:** 2c

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56 **Keywords:** flexibility, hamstring, kinesiology tape, stretching

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59 INTRODUCTION

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61 The incidence and recurrence of hamstring injuries in sport have been well
62 documented, leading to calls for a review of injury prevention strategies.¹⁻⁴ Although
63 many biomechanical and physiological components can influence the occurrence,
64 one “modifiable” risk factor that is commonly discussed is muscle flexibility.¹⁻⁶
65 Greater hamstring flexibility has been associated with reduced injury incidence in
66 sporting and military populations.^{7,8} Traditionally musculoskeletal stretching
67 protocols adopted a static stretching approach, more recently linked to detrimental
68 effects on strength and power and advocated only as an outcome measure.⁹
69 Alternative methods such as active, isometric contractions and the use of
70 proprioceptive neuromuscular facilitation (PNF) techniques have subsequently been
71 considered and used to treat a broad range of orthopaedic conditions.¹⁰ The brief

72 isometric contraction creates a reduction in muscle tension and subsequently
73 enables range of movement (ROM).¹¹

74 A more recent development within the clinical setting theorizing similar physiological
75 mechanisms is the application of kinesiology taping (KT), creating a pulling force on
76 the skin in order to attempt to enable and enhance ROM. However there remains
77 little empirical evidence for its support. Only 22% (of 72 studies) reported immediate
78 positive results for the use of KT on muscle extensibility,¹² with methodological
79 variations in application, anatomical regions, recruitment criteria and sample size
80 limiting direct comparisons between studies.

81 The temporal efficacy of intervention techniques on muscle extensibility has been
82 afforded little consideration, despite the implications for sporting performance and
83 the clinical environment. Immediate change in muscle extensibility post-intervention
84 is likely to be through increased stretch tolerance, pain gate theory, reciprocal or
85 autogenic inhibition. Thus static stretching and PNF would have an acute effect on
86 hamstring extensibility, with PNF expected to show greater gains due to the
87 increased contraction. However over a period of 30 minutes it would be expected
88 that KT would show the greater effect as the properties of the tape are activated.

89 Since tape is applied from the origin to insertion through the muscle stretch it could
90 be hypothesized that through prolonged stress relaxation and viscoelastic
91 deformation, applying a constant force over a period of time (creep) will increase
92 tissue extensibility. Although it is suggested that improving hamstring extensibility
93 decreases the injury risk, the efficacy of the improvement over time is vital to ensure
94 the extensibility is maintained through training and performance. The aim of the
95 present study was to compare the immediate, 10 minute and 30 minute post-
96 intervention efficacy of KT to traditional stretching techniques on hamstring

97 extensibility to assist practitioners in choice of intervention. It was hypothesized that
98 the temporal pattern of changes in hamstring extensibility will be unique to each
99 intervention, given their discrete mechanistic influence.

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101 **METHODS**

102 30 male participants (Mean \pm SD: age 21.0 ± 0.1 years; height 180 ± 6 cm; mass
103 79.4 ± 6.9 kg) completed the present study, with inclusion criteria requiring that each
104 participant be male between the ages of 18-22 years, participating in recreational
105 sport four times a week, asymptomatic from injury and with no history of previous
106 hamstring injury. Exclusion criteria included history of lumbar or neurological
107 symptoms, history of musculoskeletal disorders or injuries within the previous 12
108 months, medical conditions that may have altered muscle flexibility and skin allergies
109 or conditions. All participants were further screened and excluded if their straight leg
110 raise was $< 70^\circ$. The 30 participants were randomly and evenly selected into 3
111 groups defining the nature of the intervention: static stretch (SS), PNF and KT.
112 Detailed information regarding the nature and purpose of the study was provided,
113 and all participants provided written informed consent in accordance with the
114 departmental and university ethical procedures and following the principles outlined
115 in the Declaration of Helsinki.

116 ***Data Collection & Analysis***

117 All participants completed a standardized five minute warm up on the cycle
118 ergometer.¹³ Five-centimeter seat belts were placed across ASIS and the non-
119 dominant leg at 20cm above tibial tuberosity to stabilize participants during the
120 standardized Active Knee Extension (AKE) position.^{14,15} The hip was placed in to
121 90° and fixed using a seat belt, proximal to the popliteal crease (Figure 1). All belts

122 were marked for remeasurement, and the dominant leg was measured for all
123 participants.

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125 ** Figure 1 near here **

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127 The measurement of AKE was taken once the participant had actively extended the
128 knee to their point of hamstring stretch tolerance (no pain and initial resistance) and
129 at that point the calcaneus was supported to allow a baseline measurement to be
130 recorded, via a standard goniometer (Myrin, Patterson Medical, North Ryde,
131 Australia) at the tibial tuberosity.^{16,17} The participant was then placed prone on the
132 plinth with a pillow under the ankles to assist in relaxation of hamstrings.

133 Subsequent to this baseline measure, AKE measurements were completed
134 immediately, 10 minutes and 30 minutes post intervention. In SS the group barrier of
135 resistance was found in AKE and a 30 sec hamstring stretch applied, with a 10 sec
136 rest period between each stretch, repeated three times.^{18,19} The PNF group was
137 placed in AKE position and the initial stretch barrier held for 10 secs, prior to 10 secs
138 PNF contract-relax resistance of 75%. There was a three second release from
139 barrier prior to stretching to new resistance barrier for 10 secs, and this process was
140 repeated three times.²⁰ For the SS and PNF interventions the time of active
141 implementation was standardised, and this same time (5 minutes total) duration was
142 used in the KT intervention. For KT application the distributor's guidelines were
143 followed, with the area prepared and a single Y-cut application at 25% stretch,
144 applied from origin at ischial tuberosity to insertion at head of fibula, and medial
145 condyle of tibia to hamstring muscle insertion points (Figure 2). For all participants
146 and for each intervention, all procedures were performed by the same therapist.

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** Figure 2 near here **

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150 **Statistical Analysis**

151 The aim was to describe the temporal nature of improvements in hamstring
152 extensibility post-intervention. A range of regression polynomials were applied to
153 each intervention in order to quantify the strength of fit, and determine the optimum
154 model to best describe temporal efficacy. The strength of the regression was
155 determined using the r^2 value. All statistical assumptions associated with the
156 statistical methods above were explored. The statistical analyses were calculated
157 using SPSS for Windows, version 18.0 (SPSS, Inc., Chicago, IL, USA). Data are
158 presented as mean \pm standard deviation. Time subscripts are used to specify the
159 measurement time as baseline "00", immediately post-intervention "+1", 10 minutes
160 post-intervention "+10", and 30 minutes post-intervention "+30". Thus an immediate
161 post-intervention measure following the PNF intervention would be described as
162 PNF₊₁.

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164 **RESULTS**

165 ANOVA confirmed no significant differences in AKE between the three groups at
166 baseline. With the baseline score for each subject is set to 100%, repeated
167 measures ANOVA revealed a significant interaction between time and intervention
168 (Figure 3). Active knee extension scores at PNF₊₁ ($107.7 \pm 8.2\%$, $p = .01$), KT₊₁₀
169 ($106.0 \pm 7.1\%$, $p = .05$) and KT₊₃₀ ($106.9 \pm 5.0\%$, $p = .02$) were significantly higher
170 than pre-intervention measures.

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** Figure 3 near here **

To investigate the temporal pattern of changes in active knee extension with each intervention, a linear regression was initially conducted for each intervention. The regression equations used to predict active knee extension (AKE) from time after intervention (t) are summarized as follows:

KT: $AKE = 99.84 + 0.35t \quad r^2 = 0.71, p = 0.01$
SS: $AKE = 105.06 - 0.40t \quad r^2 = 0.82, p = 0.01$
PNF: $AKE = 111.75 - 0.43t \quad r^2 = 0.66, p = 0.01$

Subsequent to a forced linear regression, the polynomial was altered for each condition to investigate the optimum model to fit the changes in AKE with time after intervention. The strength of the regression was used as the parameter to select the optimum function. The best fit for each intervention is shown diagrammatically in Figure 4 and the regression equations are summarized as:

KT: Quadratic $AKE = 99.14 + 0.80t - 0.02t^2 \quad r^2 = 0.76$
SS: Linear $AKE = 105.06 - 0.40t \quad r^2 = 0.82$
PNF: Logarithmic $AKE = 115.16 - 4.25\ln(t) \quad r^2 = 0.77$

** Figure 4 near here **

DISCUSSION

196 The current study investigated the efficacy of traditional stretching techniques and
197 kinesiology tape on hamstring extensibility over a 30-minute period. Contemporary
198 reviews have found only a minimal number of studies, many of low methodological
199 quality, with KT providing no significant difference to other interventions.¹² However,
200 the temporal nature of the benefits afforded by kinesiology tape have not been
201 considered.

202 Only kinesiology tape demonstrated a positive linear correlation with time post-
203 intervention. Both static stretching and PNF demonstrated a negative relationship
204 with time, such that hamstring extensibility gradually decreased after an initial
205 improvement. This finding has implications for the practitioner, since the choice of
206 intervention might depend on the time constraints of the context. If immediate and
207 short-term improvements in hamstring flexibility are required then these findings
208 suggest that PNF is the preferable application, consistent with previous literature.²⁰
209 However, if improvement is required over a greater time period then kinesiology tape
210 offers potential benefits.

211 Few studies have considered the temporal influence of these interventions, more
212 commonly considering only the immediate effects after an application.^{21,22} The
213 positive influence of KT supports previous literature,^{23,24} but the temporal pattern of
214 changes in hamstring extensibility following the KT application was best modelled
215 with a quadratic function. The predictive quadratic equation yields a maximum active
216 knee extension score of 108.8% of baseline measure at 24.2 min post-application.
217 Further analysis of the predictive quadratic curve shows that AKE is raised to 105%
218 of baseline by 9 min post-intervention. Therefore a window of opportunity of
219 approximately 30 min exists (from +9 to +39 mins post-intervention) where AKE is
220 greater than 105% of baseline.

221 The proposed physiological mechanism is complex and incompletely understood,
222 with the majority of studies theorizing four main mechanisms to that lead to the
223 decrease in muscle tension and increased ROM; autogenic inhibition, reciprocal
224 inhibition, stress relaxation, and pain gate control theory.²⁵ The current findings
225 suggest that the immediate change in muscle extensibility is likely to be through
226 either increased stretch tolerance, pain gate theory, reciprocal or autogenic
227 inhibition. The greatest initial gains attributed to PNF advocate increased co-
228 contraction theory, with beneficial effects on surrounding anatomical structures in
229 addition to the muscle isolated for contraction. Stress relaxation with viscoelastic
230 deformation of tissue or reciprocal inhibition with contraction of the agonist and
231 antagonist may be plausible theories.²⁶ However the pain gate control theory may be
232 the most plausible, with the muscle stretched forcefully into a new end of range the
233 golgi tendon organs are activated in an attempt to reduce injury.²⁷ As the tendons
234 are stretched the muscle is contracted in a lengthened position, inhibiting pain, and
235 potentially enabling the golgi tendon organs to adapt to the new force threshold and
236 achieve an increase in length. The current results demonstrating a negative
237 correlation with time for SS and PNF suggest that if viscoelastic change has
238 occurred this is short term and is unable to be maintained. This supports previous
239 observations that post PNF intervention, muscle activity returned to 50% within one
240 second and 90% in 10 seconds.²⁸

241 The current findings that KT was the preferential intervention over 30 minutes
242 supports the proposal that KT must be applied prior to use to allow the glue
243 properties of the tape to activate. As tape is applied to the skin, it could be
244 hypothesized that any increase in tissue extensibility might be due to cutaneous
245 receptor response influencing the effects of stress relaxation and viscoelastic

246 deformation by applying a constant force over a period of time (creep). The adaptive
247 change in tissue might be due to either increased circulation in the taped area or
248 stimulation of the cutaneous mechanoreceptors to assist in tissue deformation.²⁹
249 The optimum post-intervention time derived from the regression equation appears to
250 be 24.2 mins, suggesting a combination of initial cutaneous mechanoreceptor
251 stimulation and viscoelastic change that may assist in deformation over time. The
252 mechanisms underpinning stretch tolerance and the influence of sensory neural
253 pathways remain unclear. Changing muscle extensibility can increase the number of
254 sarcomeres and stimulate the rearrangement of collagen through adaptive change
255 and deformation of tissue.³⁰
256 The current study used healthy, recreationally active male participants, kinesiology
257 tape is increasingly popular to assist in prevention, technique improvement and
258 performance facilitation.³¹ It must also be considered that an increase in muscle
259 extensibility may be detrimental to power and performance, and may actually
260 increase injury risk.^{2,32} The current findings cannot be generalized to a wider
261 population according to age, gender and health of the subjects. The findings are
262 also specific to the nature of the interventions, and the measure of active knee
263 extension. In this respect further research is encouraged to explore both the
264 potential benefits of kinesiology tape, and the physiologic explanatory mechanisms.
265 Electromyographical analysis of the muscular response would further develop the
266 understanding of the mechanistic influence of kinesiology tape. Furthermore, any
267 observed changes in the contractile properties of the hamstring musculature are
268 likely to have an ipsilateral influence on the quadriceps for example. Changes in the
269 hamstring:quadriceps strength ratio would subsequently influence the dynamic
270 control ratio of the knee joint. Lower limb mechanics are therefore likely to be

271 influenced more generally by localized changes to the hamstrings. Likewise, the
272 function of the hamstrings is likely to influence changes in the gluteal and core
273 musculature via the posterior chain. The benefits of kinesiology tape are likely to be
274 influenced by a range of extrinsic factors to include the environment, nature of injury,
275 population, sporting demands, physiological, psychological, and biomechanical
276 characteristics, as well as therapist experience. Efficacy will also be directly related
277 to the execution of the techniques; duration, intensity, and reliability of application.²⁸
278 Future studies should consider longitudinal studies, assessment of effects on
279 additional muscle groups, functional task assessment, and alternative tape
280 application methods.

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282 **CONCLUSION**

283 This study has modelled the temporal changes in active knee extension to contrast
284 the efficacy of kinesiology tape, static stretching, and PNF. The choice of
285 intervention should consider the temporal context of the scenario. For an immediate
286 improvement in hamstring extensibility PNF is preferable, but for advantages over a
287 longer duration (up to 30 minutes in this study) kinesiology tape is advantageous.
288 The optimum timing of kinesiology tape application was 24 minutes prior to
289 assessment of hamstring extensibility.

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392 **LEGENDS TO FIGURES**

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394 Figure 1. The Active Knee Extension testing position.

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396 Figure 2. The Kinesiology Tape Y-cut application.

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398 Figure 3. The time history of changes in active knee extension with each
399 intervention. * denotes significantly greater than baseline ($p \leq 0.05$).

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401 Figure 4. The optimum correlational function to model the time history of changes in
402 active knee extension for each intervention.

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405 Figure 1. The Active Knee Extension testing position.

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Figure 2. The Kinesiology Tape Y-cut application.

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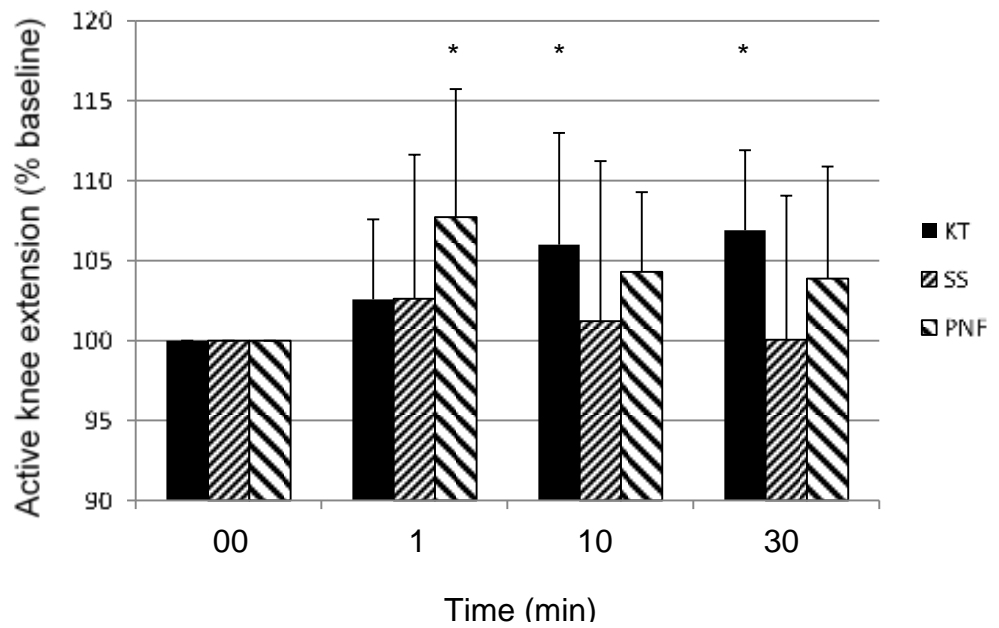


Figure 3. The time history of changes in active knee extension with each intervention. * denotes significantly greater than baseline ($P \leq 0.05$).

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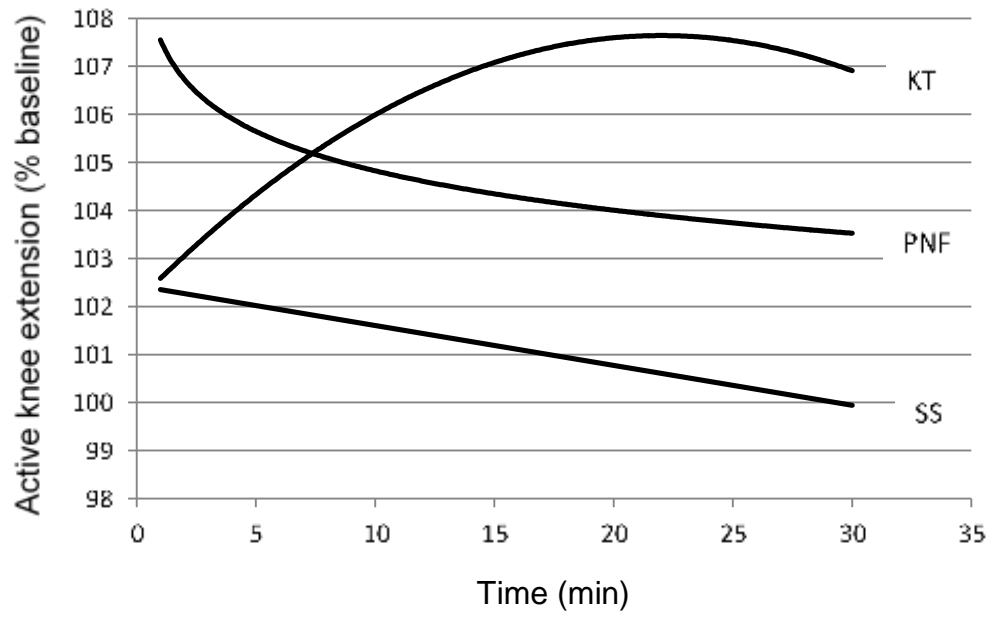


Figure 4. The optimum correlational function to model the time history of changes in active knee extension for each intervention.

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