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1 **An exploration of normative values in New Zealand to inform the Targeted**
2 **Interventions for Patellofemoral Pain approach**

3

4 *Original research using quantitative data*

5

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65

ABSTRACT

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67

68 Background: The Targeted Interventions for Patellofemoral Pain studies (TIPPs) have
69 identified three subgroups exist in UK and Turkish patellofemoral pain (PFP)
70 populations: Strong; Weak and Tight; and Weak and Pronated, based on six clinical
71 assessments. The thresholds used to develop the subgrouping algorithms were based on
72 normative values sourced from various populations and countries.

73

74 Objectives: Explore normative scores from the clinical assessments in a singular non-PFP
75 population whilst considering potential differences between ethnicities and sex (primary
76 aim). Revisit inter-rater reliability of each assessment (secondary aim).

77

78 Design: Cross-sectional and test-retest.

79

80 Method: The six assessments; rectus femoris length, gastrocnemius length, patellar
81 mobility, hip abductor strength, quadriceps strength, and Foot Posture index (FPI) were
82 measured in 89 New Zealanders (34% Māori, 45% female). Two raters independently
83 assessed 17 participants to examine inter-rater reliability.

84

85 Results: Significant interactions between ethnic group and sex were noted for rectus
86 femoris length and patella mobility. Māori versus European males exhibited greater rectus
87 femoris tightness ($p = 0.001$). Māori versus European females demonstrated greater
88 patellar mobility ($p = 0.002$). Females were significantly weaker than males in normalised
89 strength measures ($p < 0.001$), and had lower FPIs. Mean differences between testers for

90 all measures were small and not significant, except for FPI which had a 2.0 point median
91 difference ($p = 0.021$).

92

93 Conclusions: Our results indicate that sex is an important factor worth considering within
94 the TIPP's subgrouping approach, more than ethnicity, especially for the normalised
95 strength measures. The sub-optimal reliability of FPI warrant reconsideration of its
96 inclusion within TIPP's.

97

98 **Keywords**: ethnicity, knee, physiotherapy, normative data.

99

100

HIGHLIGHTS

101

- The Targeted Interventions for Patellofemoral Pain algorithm uses 6 clinical
102 tests

103

- The algorithm identifies three patellofemoral pain (PFP) subgroups

104

- There was no main effect of ethnicity (Māori vs NZ European) on clinical scores

105

- Sex differences in the 2 strength tests warrant a sex-based stratification approach

106

- The suboptimal Foot Posture Index reliability queries its inclusion in the

107

algorithm

INTRODUCTION

108

109

110 Patellofemoral pain (PFP) is a challenging clinical condition with a wide variety of
111 theories postulated to explain casual mechanisms (Janssen 2017). Despite the publication
112 of clinical practice guidelines (Willy et al. 2019) and consensus statements (Collins et al.
113 2018), no standardised treatment approach for PFP existed. Given that it takes on average
114 17 years for research to be translated into practice (Morris, Wooding, and Grant 2011),
115 current physiotherapy management of PFP varies and frequently relies on a trial-and-error
116 multimodal approach that includes exercise therapy, patellar taping, bracing, and foot
117 orthoses (Smith et al. 2017; Collins et al. 2018). An international consensus has
118 highlighted the need for musculoskeletal studies to adopt subgrouping approaches to
119 improve our understanding of the underlying mechanisms and optimise patient
120 management (Foster et al. 2009). This consensus highlighted that the heterogeneity of
121 patient samples in previous studies has led to findings of small or no treatment effect,
122 with inferences that non-pharmacological interventions in musculoskeletal conditions
123 might lead to little patient benefit. Indeed, the majority of randomised control trials
124 indicate no clinical benefit of conservative treatment over placebo, sham, or other
125 approaches in reducing PFP symptomatology (Saltychev et al. 2018). However, such
126 heterogeneity may be masking a range of individual responses and true treatment effects.

127

128 Subgrouping approaches have proved effective for optimising management in other
129 musculoskeletal conditions, such as low back pain (Brennan et al. 2006; Hill et al. 2011),
130 and there is growing agreement from academics and clinicians on the potential benefit of
131 delivering tailored interventions to improve PFP outcomes (Lack et al. 2018). A recent

132 review summarises the range of PFP subgrouping approaches, and highlights that no
133 consensus yet exists on the number or best classification approach to PFP subgroups
134 (Selfe et al. 2018). The majority of classification systems are of limited use because they
135 do not include clear diagnostic criteria for each subgroup, or they rely on imaging or
136 surgical findings that may not always be available to clinicians (Willy et al. 2019).

137

138 Our research team commenced the **T**argeted **I**ntervention for **P**atellofemoral **P**ain studies
139 (TIPPs) programme to investigate potential PFP subgroups that were: (1) identified by
140 simple evidence-based clinical tests; (2) based on tests that clinicians could use routinely
141 in a variety of settings, e.g., from primary care facilities to teaching hospitals; (3) based
142 on assessments that required minimal expertise and training for competent performance,
143 and involved no or low-cost equipment; (4) based on published thresholds for potentially
144 important factors that could be used to assign patients to specific subgroups; and (5)
145 matched to a specific and credible treatment intervention for each identified subgroup
146 (Selfe et al. 2013). The thresholds used to develop the TIPPs algorithms (Selfe et al.
147 2013) were based on published normative values sourced from the literature, and were
148 hence derived from a range of studies and populations from various countries (Maffiuletti
149 2010; Witvrouw et al. 2000; Redmond, Crane, and Menz 2008; Herrington, Malloy, and
150 Richards 2005; Youdas et al. 2005). Normative data derive from a reference population
151 and establish a baseline distribution for a score or measurement, and against which the
152 score or measurement can be compared (Campbell 2013).

153

154 From this work, three hypothesis-driven subgroups emerged: (1) Strong; (2) Weak and
155 Tight; and (3) Weak and Pronated (Selfe et al. 2016). Continued work in this area has led

156 to the development of a subgrouping algorithm based on objective data generated by six
157 low-cost clinical tests to categorise PFP patients into one of these three subgroups. The
158 algorithm and subgroup allocation are delivered to clinicians via the Appatella™ mobile
159 application (DigitalLabs@MMU 2019). This approach to PFP subgrouping suggests that
160 it is ecologically valid as it has high clinical value due to its low-cost and accessibility,
161 making it potentially viable for widespread implementation in primary care and
162 physiotherapy clinics internationally.

163

164 The Prognosis Research Strategy (PROGRESS) partnership (Hingorani et al. 2013a) and
165 the Medical Research Council (2018) provide recommendations on development, design,
166 and analysis in stratification research. Both frameworks suggest an initial hypothesis
167 setting stage, which defines the problem and population. Thereafter, recommendations
168 are to progress to identifying the variables that define subgroups and then gain an
169 understanding of the properties of the tests. Researchers are encouraged to continue
170 considering implementation of tests from both a patient and health professional
171 perspective. These considerations help direct the choice of tests, number of subgroups,
172 analytical approaches, and thresholds for patient subgroup allocation. Approaches based
173 on targeted interventions, such as the TIPP's framework, require thorough evaluation and
174 exploration of the potential mechanisms and biological reasons underpinning
175 individualised treatment responses (Hingorani et al. 2013b).

176

177 In line with these recommendations, we embarked on the present study to understand
178 further the properties of the clinical assessments used in the TIPP's algorithm, and notably
179 to verify the normative values in a given population. Our primary aim was to explore the

180 clinical assessment scores from a non-PFP population outside of the United Kingdom
181 (Selfe et al. 2016) and Turkey (Yosmaoğlu et al. 2020), i.e., countries where previous
182 work on TIPP's has been undertaken in PFP populations, whilst considering ethnicity and
183 sex. Since the original TIPP's thresholds stem from various normative population groups,
184 this exploration may help refine the approach by verifying the normative values of all the
185 clinical assessments included in the TIPP's within a singular population of non-injured
186 individuals. Given that reliability of measures depends on sample characteristics
187 (Matheson 2019), our secondary aim was to revisit the inter-rater reliability of the
188 individual clinical assessments of the TIPP's algorithm within this singular cohort of
189 individuals.

190

191 **MATERIALS AND METHODS**

192

193 **Participants**

194

195 Normative data characterise what is typical in a defined population. In the context of PFP,
196 young active adults are a suitable population to define normative values for TIPP's
197 benchmarking considering that PFP typically manifests in young physically active
198 populations (Smith et al. 2018). Previous TIPP's research has involved 95 to 127
199 individuals (Yosmaoğlu et al. 2020; Selfe et al. 2016), with normative reference data from
200 clinical gait analysis services derived from 81 participants (Pinzone et al. 2014). With this
201 in mind, we sought to recruit a minimum of 80 individuals to establish normative values
202 from a university-aged population to reflect young active individuals.

203

204

205 Of the 196 undergraduate university students in the Health, Sport and Human
206 Performance programme at the University of Waikato who were invited to participate via
207 an online forum, 89 voluntarily accepted to participate and completed all TIPP
208 assessments. All 89 participants were invited to participate in the inter-rater reliability
209 component of this study, with a subgroup of 17 individuals agreeing to participate. All
210 recruitment and data collection processes were undertaken within a 4-week period in the
211 month of May 2019. For inclusion, participants needed to be free from injury, pain, or a
212 medical contraindication to physical activity. All participants signed an informed consent
213 document prior to participation. The study protocol was approved by the local University
214 human ethics committee [UoW HREC(Health)#2017-54], which was conducted in
215 accordance with international ethical standards (Harriss, Macsween, and Atkinson 2017),
216 adhered to The Code of Ethics of the World Medical Association (*Declaration of*
217 *Helsinki*), and prepared in accordance with the Strengthening the Reporting of
218 Observational studies in Epidemiology (STROBE) studies guidelines for cross-sectional
219 studies (von Elm et al. 2007).

220

221 Study design

222

223 This cross-sectional study aimed to establish a dataset from a New Zealand (NZ)
224 population and allowed the exploration of potential differences between the two main
225 ethnic groups (Māori and NZ European) and sex. Data were collected across two sessions,
226 7 days apart, due to the availability of the participants and physiotherapists. We used a
227 standard test-retest design to establish inter-rater reliability from $n = 17$ participants, with

228 two qualified physiotherapists with more than 3 years of experience assessing each
229 participant 60 minutes apart. The physiotherapists were blinded to each other's measures
230 to reduce bias. Assessments were conducted in a movement laboratory using medical
231 plinths, standard universal goniometers, cloth metric tapes, stabilisation straps, and a
232 Lafayette Hand-Held Dynamometer (Model 01165, range: 0 – 136.1 kg, resolution: 0.1
233 kg, Lafayette Instrument Company, IN, USA). We assessed the dominant leg only,
234 defined as the preferred leg to kick a ball. Four of the 89 individuals were left-leg
235 dominant. All test-retest participants were right-leg dominant, with test conducted in a
236 random order between the two therapists.

237

238 Similar to previously conducted TIPP studies (Selfe et al. 2013; Selfe et al. 2016), the
239 two qualified physiotherapists collecting the clinical measures undertook a series of
240 comprehensive personalised training sessions. These sessions involved training on the
241 research processes and on how to undertake the standardised clinical tests. Experts in the
242 field led and observed the physiotherapists during these sessions and provided peer
243 feedback. The physiotherapists were given a comprehensive manual outlining standard
244 operating procedures and standardised data recording forms.

245

246 Clinical assessments

247

248 The TIPP algorithm includes six clinical assessments (Selfe et al. 2016): (1) passive
249 prone knee flexion (rectus femoris length) (Witvrouw et al. 2000); (2) calf flexibility
250 standing method (gastrocnemius length) (Witvrouw et al. 2000); (3) hip abductor
251 strength (Maffiuletti 2010); (4) quadriceps (knee extension) strength (Maffiuletti 2010);

252 (5) patellar mobility (medial plus lateral glide) using the patellar glide test (Witvrouw et
253 al. 2000; Janssen et al. 2019); and (6) foot pronation using the Foot Posture Index (FPI)
254 (Redmond, Crane, and Menz 2008). The two physiotherapists conducting the clinical
255 assessments attended three training sessions, conducted a series of practice assessments
256 using the Appatella™ mobile application (DigitalLabs@MMU 2019), and were given a
257 manual outlining the assessment procedures. A brief summary of each clinical assessment
258 is provided (**Table 1**) given that these procedures are presented in detail elsewhere (Selfe
259 et al. 2013).

260

261 Statistical analysis

262

263 All data were examined using Shapiro Wilk tests and found to be suitable for parametric
264 analysis, except the FPI. For the muscle length, strength, and patellar mobility
265 assessments, univariate analyses were performed to explore the effect of ethnicity (Māori,
266 NZ European), sex (males, females), and their interaction on outcomes. Post-hoc pairwise
267 comparisons were performed where significant main effects were observed, and mean
268 differences with 95% confidence intervals [lower, upper] were calculated. For the FPI,
269 Mann-Whitney U tests were performed between ethnic groups and sexes, and the median
270 value with 25th and 75th percentiles was calculated. Data from all 89 and 17 participants
271 were available for analysis from the normative and reliability samples (i.e., no missing
272 data).

Table 1. Overview of the procedures for each of the six clinical assessments used in the TIPP's algorithm.

Name	Method	Equipment	Outcome	Summary of procedure
Rectus femoris length	Passive prone knee bend	Universal goniometer	Knee angle (°)	Patient prone on a plinth. Foot of non-tested leg on the floor with hip at 90°. Knee of tested leg passively flexed maximally (Norkin and White 2016; Witvrouw et al. 2000).
Gastrocnemius length	Calf flexibility standing method	Universal goniometer, tape measure	Ankle angle (°)	Patient faces wall with toes of tested leg 60 cm away and knee straight. Tested leg parallel with and behind non-tested leg (i.e., toes of tested leg level with heel of non-tested leg). Hands on wall for support. Keeping heel on floor, ankle of tested leg flexed maximally (Norkin and White 2016; Witvrouw et al. 2000).
Patellar mobility	Patellar glide (medial – lateral)	Tape measure, felt pen	Total displacement (cm)	Patient supine with quadriceps relaxed and knees straight. Medial force applied to lateral border of patella. Maximal displacement of patella pole marked. Lateral force then applied to medial border of patella. Maximal displacement of patella pole marked. Distance between maximal displacements recorded (Witvrouw et al. 2000; Janssen et al. 2019).
Hip abductor strength (normalised to body weight)	Maximum voluntary isometric strength test	HHD, tape measure	Moment (Nm/kg)	Patient side lying with legs in neutral position. Test leg on top with stabilising strap around test leg and plinth, adjusted to ensure neutral position during effort. HHD under strap. Patient abducts test leg towards ceiling, applying maximum force against HHD for 3 s. Foot remains parallel to ceiling (i.e., no hip rotation). Maximum from 3 tests done 20 s apart used. Moment arm measured as distance from hip-joint axis (i.e., proximal part of greater trochanter) to HHD (Selfe et al. 2016).
Quadriceps strength (normalised to body weight)	Maximum voluntary isometric strength test	HHD, tape measure	Moment (Nm/kg)	Patient seated with knee at 90° over edge of plinth. HHD under strap, perpendicular to tibia, proximal to the malleoli. Patient extends test knee, applying maximum force against HHD, holding sides of plinth for stability. Maximum from 3 tests done 20 s apart used. Moment arm measured as distance from knee-joint axis (i.e., lateral femoral epicondyle) to HHD (Maffiuletti 2010).
Foot pronation	Foot Posture Index	None	Number between -12 to +12	Patient relaxed standing, double limb support. Six items assessed: (1) talar head palpation; (2) lateral malleolar curvature; (3) calcaneal frontal plane position; (4) prominence in the region of the talonavicular joint; (5) congruence of the medial longitudinal arch; (6) abduction/adduction of forefoot on rearfoot. Each item scored from -2 to +2, with positive values indicating greater pronation (Redmond, Crosbie, and Ouvrier 2006).

Notes. Abbreviations: HHD, handheld dynamometer. TIPP's, Targeted Intervention for Patellofemoral Pain studies.

RESULTS

Participants

The demographic characteristics of the 89 participants included in the normative database (35% Māori, 45% female) and subgroup of 17 participants included in the inter-rater reliability analysis (29% Māori, 29% female) are presented in **Table 2**.

Table 2. Demographic characteristics of participants contributing to the TIPP norms normative database ($n = 89$) and inter-rater reliability analysis ($n = 17$).

Characteristic	Normative database		Inter-rater reliability	
	Male ($n = 49$)	Female ($n = 40$)	Male ($n = 12$)	Female ($n = 5$)
Age (years)	19.6 (2.1)	19.4 (1.7)	21.7 (4.3)	22.0 (4.0)
Height (cm)	180.7 (9.4)	167.9 (5.7)	173.3 (12.4)	166.8 (4.3)
Mass (kg)	84.7 (15.4)	67.7 (7.6)	78.4 (14.5)	69.6 (9.2)
Māori (n)	37% (18)	30% (12)	33% (4)	20% (1)

Notes. Values are mean (SD). Abbreviations: SD, standard deviation; TIPP, Targeted Intervention for Patellofemoral Pain studies.

Normative database

The univariate analyses showed significant interactions between sex and ethnic group for rectus femoris length and patellar mobility (**Table 3**). Post-hoc pairwise comparisons indicated significant differences in rectus femoris length in males only, with Māori showing greater muscle tightness (mean difference: 7.0° [2.9, 11.1], $p = 0.001$). For patellar mobility, a significant difference was seen within females only, with the Māori group showing greater patellar mobility (mean difference: 4.4 mm [1.6, 7.3], $p = 0.002$). No other differences were seen between ethnic groups for any of the clinical assessment

185 measures. In addition, females were significantly weaker than males in both normalised
186 quadriceps (mean difference: -0.36 Nm/kg [-0.52, -0.20], $p < 0.001$) and hip abductor
187 (mean difference: -0.425 Nm/kg [-0.62, -0.23], $p < 0.001$) strength measures, and
188 demonstrated less pronated foot postures on the FPI (median difference: -2.0 points, z-
189 score -2.277, $p = 0.023$), **Table 3**.

190

191 Inter-rater reliability

192

193 Descriptive statistics from the inter-rater reliability assessments are presented in **Table 4**.

194 There were no significant differences between the testers for the clinical measures, except

195 for the FPI (median difference: 2.0 points, **Table 4**). The muscle strength and rectus

196 femoris length measures showed ‘excellent’ reliability between the two testers, whereas

197 the gastrocnemius length and patellar mobility correlation metrics indicated ‘fair to good’

198 reliability (**Table 4**). The Bland-Altman plots showed that in all measures, excluding FPI,

199 mean differences between the two testers were small (**Figure 1**). Noteworthy are the

200 relatively wide limits of agreement for all measures, especially the patellar mobility

201 (width of 2.1 cm), rectus femoris length (width of 28°), and gastrocnemius length (width

202 of 14°).

Table 3. Descriptive statistics for each of the six clinical assessments used in the TIPPs algorithm presented by sex and ethnic group. Results from univariate analyses, Mann-Whitney U tests, and post-hoc comparisons indicated.

	Females			Males		
	Māori (<i>n</i> = 12)	NZ European (<i>n</i> = 28)	All (<i>n</i> = 40)	Māori (<i>n</i> = 18)	NZ European (<i>n</i> = 31)	All (<i>n</i> = 49)
Rectus femoris length (°)†	132.2 (10.7)	130.0 (6.8)	130.6 (8.1)	123.6 (7.2)†	130.6 (8.1)†	128.0 (7.2)
Gastrocnemius length (°)	19.7 (2.9)	20.5 (4.7)	20.3 (4.2)	21.4 (4.3)	21.3 (3.9)	20.9 (4.1)
Patellar mobility (mm)†	24.1 (3.4)†	19.6 (4.4)†	21.0 (4.6)	19.1 (6.3)	21.7 (4.4)	21.0 (5.0)
Hip abductor strength (Nm/kg)*	1.75 (0.51)	1.49 (0.40)	1.57 (0.44)	2.07 (0.38)	2.03 (0.44)	2.04 (0.41)
Quadriceps strength (Nm/kg)*	1.95 (0.42)	1.99 (0.33)	1.98 (0.36)	2.27 (0.35)	2.34 (0.34)	2.40 (0.36)
Foot Posture Index*	2.00 (0.25, 4.75)	1.00 (-2.00, 4.00)	2.00 (0.00, 4.00)	5.00 (3.00, 6.00)	3.00 (1.00, 6.00)	4.00 (1.00, 6.00)

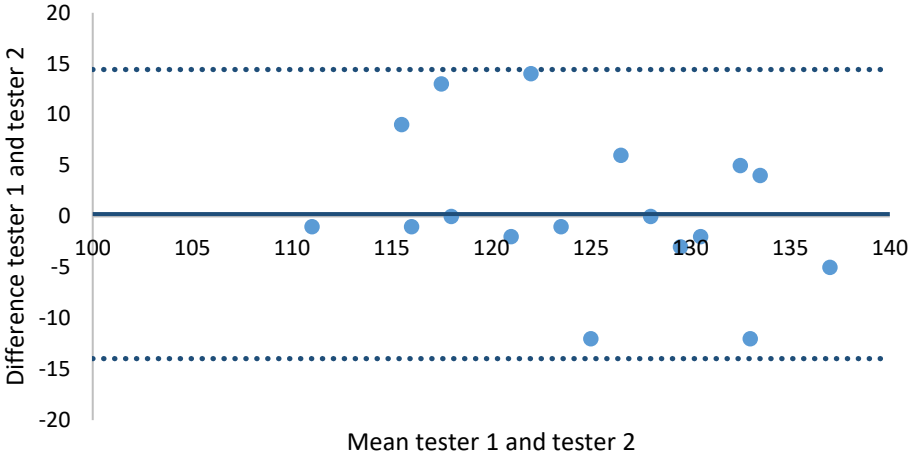
Notes. Values are mean (SD), except for the Foot Posture Index where values are displayed as median (25th, 75th percentiles). † Significant interaction between ethnic group and sex. * Significant difference between males and females. † Significant difference between Māori and NZ European during post-hoc comparisons. Significance set at $p \leq 0.05$. Abbreviations: NZ, New Zealand; SD, standard deviation.

Table 4. Inter-rater reliability descriptive statistics from 17 participants for each of the six clinical assessments used in the TIPP's algorithm presented for the two testers. Results from paired t-test and related samples Wilcoxon Signed Rank test comparisons between testers indicated.

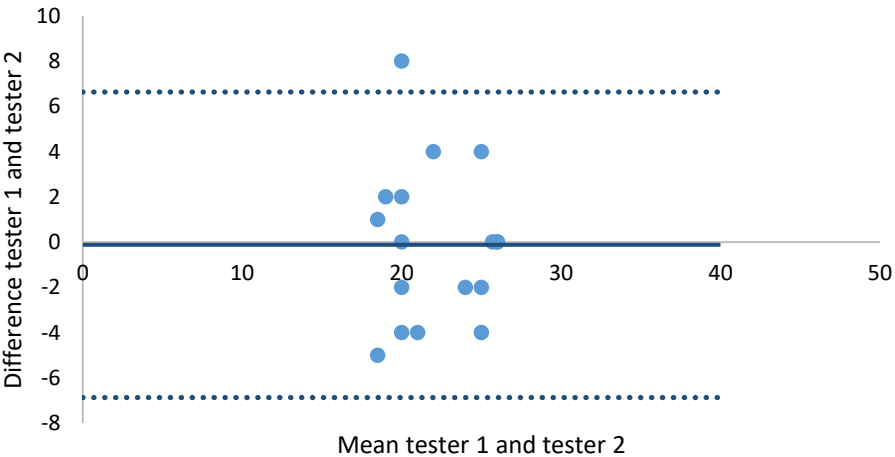
Variable	Tester 1	Tester 2	Difference	<i>t</i> -statistic	<i>p</i> -value	ICC [lower, upper]
Rectus femoris length (°)	124.8 (7.5)	124.6 (9.1)	0.24 (7.24)	0.134	0.895	0.777 [0.368, 0.920]
Gastrocnemius length (°)	22.0 (3.3)	22.2 (3.4)	-0.12 (4.39)	-0.141	0.890	0.652 [0.001, 0.875]
Patella mobility (mm)	19.5 (6.3)	19.2 (5.4)	0.4 (5.4)	0.270	0.791	0.745 [0.280, 0.909]
Hip abductor strength (Nm/kg)	1.67 (0.51)	1.62 (0.54)	0.05 (0.37)	0.600	0.557	0.867 [0.635, 0.952]
Quadriceps strength (Nm/kg)	2.22 (0.46)	2.14 (0.51)	0.07 (0.36)	0.834	0.416	0.846 [0.581, 0.944]
Foot Posture Index †	5.00 (2.50, 7.50)	3.00 (-1.50, 5.50)	-2.0 (-1.0, 4.0)	-2.299	0.021*	nc

Notes. Values are mean (SD), 95% confidence intervals [lower, upper]. † For the Foot Posture Index, related samples Wilcoxon Signed Rank test was used for comparisons, values are displayed as median (25th, 75th percentiles). * Significant difference between testers. Abbreviations: ICC, intra-class correlation coefficient; nc, not calculated.

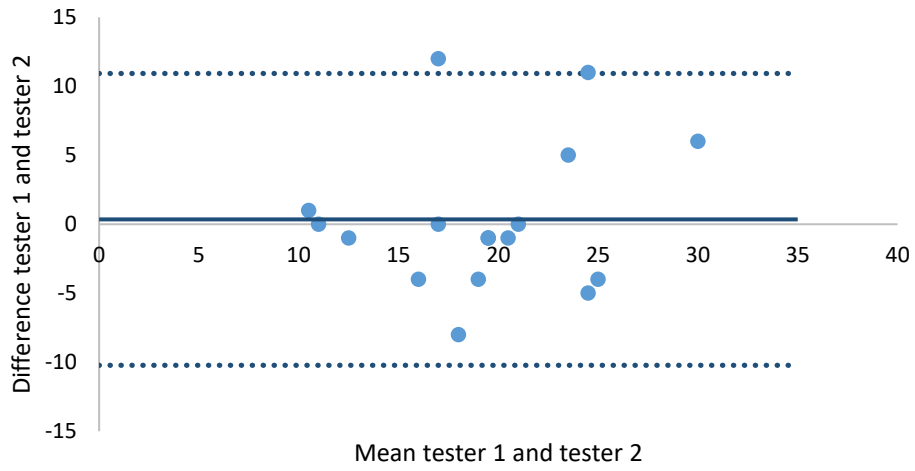
(A) Rectus femoris length (°)



(B) Gastrocnemius length (°)

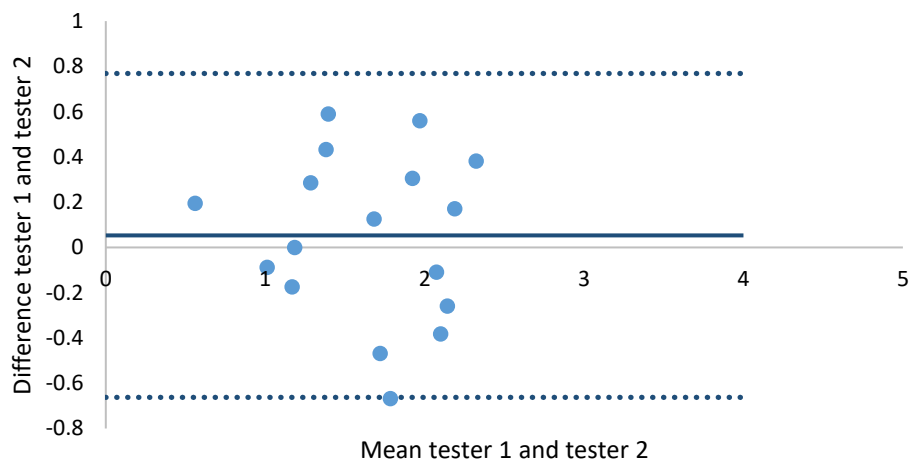


(C) Patellar mobility (mm)



C

(D) Hip abductor strength (Nm/kg)



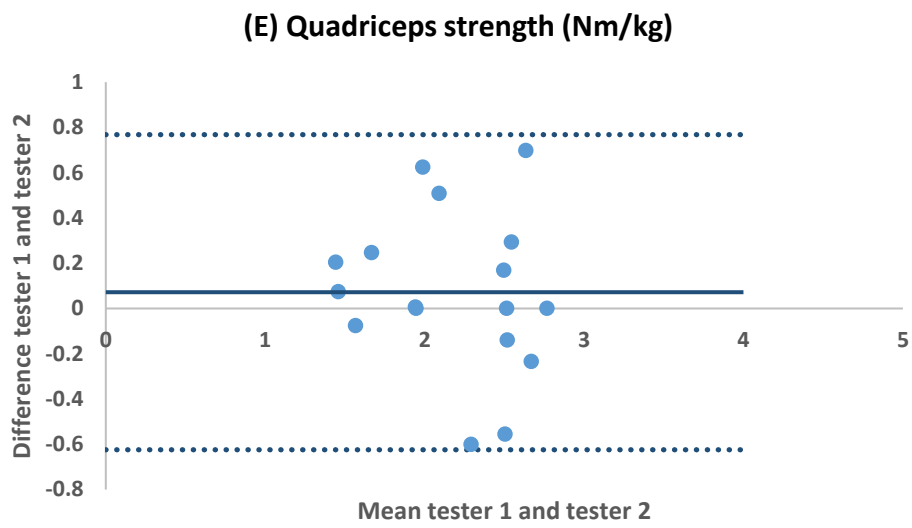


Figure 1. Bland and Altman plots with limits of agreements for: (A) rectus femoris length ($^{\circ}$), (B) gastrocnemius length ($^{\circ}$), (C) patellar mobility (mm), (D) hip abductor strength (Nm/kg), and (E) quadriceps strength (Nm/kg).

DISCUSSION

203

204

205 New Zealand university students are culturally and ethnically diverse (Taylor et al. 2017).

206 It was hypothesised that ethnic differences might be seen within this population in the

207 TIPP's subscales, warranting population-specific cut-off scores within the TIPP's

208 algorithm. In multi-ethnic countries, studies have identified differences in knee pain

209 between ethnic groups and sex, highlighting the potential for population-specific risk

210 factors (Veerapen, Wigley, and Valkenburg 2007). Māori versus NZ European males

211 exhibited greater rectus femoris tightness, with Māori versus NZ European females

212 demonstrating greater patellar mobility. Else, there were no main effects of ethnic group

213 in the TIPP's subscales, which would agree with the similar articular mobility (Klemp,

214 Williams, and Stansfield 2002) and grip strength (Teh et al. 2014) levels observed

215 between these two ethnic groups. Using the same TIPP's assessment technique, Gichuru

216 et al. (2020) found differences between UK and Turkish population groups related to foot

217 pronation attributed to a highly supinated Turkish sample. Despite suggestions that

218 healthy Māori may be predisposed to more pronated and flatter feet than NZ Europeans

219 (Gurney et al. 2012) and different plantar loading patterns (Gurney, Kersting, and

220 Rosenbaum 2009) based on Harris mat measures (static foot morphology) and pressure

221 distribution during walking (dynamic foot function), FPI values were similar between

222 groups. The similarities in FPI outcomes between groups might be in part due to the

223 relatively poor reliability we observed in this measure between testers. These results

224 suggest an alternative assessment method to identify foot pronation in the TIPP's and

225 allocate individuals to the "Weak and Pronated" subgroup should be considered, such as

226 Harris mat (Gurney et al. 2012) or midfoot mobility (McPoil et al. 2009) methods.

227

228 There are relatively few studies comparing physical fitness attributes between ethnic
229 groups within a NZ context (Quarrie and Williams 2002; Rush et al. 2007). Māori and
230 NZ European demonstrate different body composition and anthropometric
231 characteristics, with greater fat-free mass and lesser appendicular fat mass in Māori (Rush
232 et al. 2007). The normalisation of isometric strength measures to body mass accounted
233 for some of these distinct anthropometric characteristics, with no difference between
234 ethnic groups seen in normalised quadriceps and hip abductor strength. Females,
235 however, remained weaker compared to males despite normalisation. Males are overall
236 stronger (Courtright et al. 2013) and have proportionally larger muscles (Janssen et al.
237 2000) than females. A previous study on quadriceps muscle strength using a similar
238 methodology to the one presented here found ~20% lower strength in females than males
239 (Weng et al. 2015), consistent with the difference seen here. These findings suggest that
240 normalisation of lower body strength measures to body mass might be insufficient to
241 account for the established sex strength differences (Courtright et al. 2013), warranting
242 stratified algorithms based on sex within the TIPP's algorithm. The separate consideration
243 of sex is important given that the prevalence of PFP is greater in females than males across
244 a wide range of populations, from adolescents to military (Smith et al. 2018).

245

246 There is a paucity of reliability and validity data for a number of tests to assess passive
247 accessory motion of the patella relative to the femur (Willy et al. 2019). The data
248 generated in this study help to address this issue. For the patellar mobility test, the ICC
249 for inter-tester reliability was 'fair to good', and the Bland-Altman plots showed that the
250 mean difference between the two testers was small. The two testers recorded a mean

251 (SD) patellar mobility value of 19.5 (6.3) and 19.2 (5.4) mm. These values are consistent
252 with a previous UK report using identical methodology where the mean patellar mobility
253 of 44 knees in 22 healthy participants was 16.4 (5.3) mm (Janssen et al. 2019). Together,
254 these findings indicate that measuring patellar mobility using the total medial-lateral
255 patellar glide test is reliable and support its inclusion in the TIPP's subgrouping algorithm
256 and use to guide clinical management.

257

258 One of the identified clinical challenges in the management of PFP is the identification
259 of hip and thigh muscle weakness using accurate strength measures (Willy et al. 2019).
260 Maximum voluntary isometric quadriceps strength quantified using an isokinetic
261 dynamometer is highly reliable between testers (ICC = 0.97 to 0.98) (Chmielewski et al.
262 2004), but such a tool is not accessible to the majority of clinicians and researchers.
263 Isometric muscle strength testing using a handheld dynamometer is less expensive and
264 more accessible to practitioners, and has been the most widely used assessment tool for
265 this purpose (Van Cant et al. 2014). The reliability and validity of measures from HHD
266 rely on proper testing methods and stabilisation. HHD with belt stabilisation to assess
267 knee and hip maximal isometric strength has been shown as reliable (Florencio et al.
268 2019; Hansen et al. 2015; Ishøi, Hölmich, and Thorborg 2019) and valid in comparison
269 to isokinetic (Hansen et al. 2015) HHD without belt stabilisation (Florencio et al. 2019),
270 albeit providing corresponding lower (Hansen et al. 2015) and higher (Florencio et al.
271 2019) values. Our reliability data align with previous reports, with ICC values of 0.85 to
272 0.87 and 'excellent' correlation between testers. These data suggest that muscle strength
273 testing with an HHD with belt stabilisation is valid and reliable and supports its inclusion
274 in the TIPP's subgrouping algorithm, although this is not necessarily interchangeable with

275 values collected using isokinetic dynamometers or HHD without stabilisation (Weng et
276 al. 2015).

277

278 The rectus femoris (ICC 0.777) and gastrocnemius (ICC 0.652) muscle length tests
279 demonstrated ‘fair to good’ inter-rater reliability based on ICCs. Our inter-tester
280 reliability for rectus femoris appears low compared to other work using similar
281 methodology (ICC 0.91) (Piva et al. 2006), and in the mid-range of the breadth of ICCs
282 values reported for gastrocnemius muscle length testing (ICC 0.29 to 0.92) (Willy et al.
283 2019; Barton et al. 2010). The variability and differences in results seen here may be
284 related to a number of factors, such as how much therapists ‘push’ at the end of range
285 during rectus femoris length assessment, and on how participants interpret the instructions
286 for both the gastrocnemius and rectus femoris length tests. For example, the perception
287 of ‘pain’ or ‘discomfort’ may vary between individuals, and affect the outcomes of length
288 assessments. These are issues that future studies using these assessments need to be aware
289 of and determine if these can be mitigated through training. For the TIPP’s algorithm, the
290 relatively lower reliability of the gastrocnemius muscle length test with a ‘fair to good’
291 inter-rater reliability compared to the strength measures with ‘excellent’ correlations
292 indicates that the sensitivity to detect between the “Weak and Tight” and “Weak and
293 Pronated” is not as robust as detecting between the “Strong” and both “Weak” groups.

294

295 The FPI is the only test that relies on subjective clinical observations in the TIPP’s, with
296 the remainder resulting in a specific objective measurement. The FPI is an aggregate of 6
297 separate observations, which is reported to help overcome this subjectivity. Despite
298 demonstrated validity against three-dimensional (Patel et al. 2020) and radiographic

299 (Hegazy et al. 2020) imaging, our results indicate a mean difference in FPI scores of
300 around 2 points between testers, which suggest that the difference we observed in FPI
301 between sex is within tester error. Cornwall et al. (2008) found similar between-tester
302 differences and cautioned against using the FPI. In clinical practice, this variation in FPI
303 might influence foot posture categorisation, as well as orthotic prescription and
304 management. Although our two examiners were qualified physiotherapists with over 3
305 years of experience and were suitably trained in the use of the FPI, their relative
306 inexperience with the FPI likely had a negative impact on the inter-tester reliability
307 outcome (Cornwall et al. 2008). Preliminary evidence had suggested that midfoot
308 mobility measures may predict PFP patients who respond favourably to foot orthoses
309 (Vicenzino et al. 2010; Matthews et al. 2017; Mills et al. 2012), which could be a potential
310 alternative to the FPI in the TIPPs. One method to calculate midfoot mobility involves
311 recording the change in midfoot width measured at 50% of the total foot length between
312 non-weight bearing and weight bearing. ‘Excellent’ inter-rater (ICC > 0.83) and intra-
313 rater (ICC > 0.97) reliability has been reported for this measure (McPoil et al. 2009). A
314 recent randomised clinical trial, however, reported no association between midfoot
315 mobility and treatment outcomes from using foot orthoses versus hip exercise (Matthews
316 et al. 2020), indicating that perhaps foot width measure might not necessarily be a better
317 alternative to the FPI for subgroup allocation via the TIPPs algorithm.

318

319 We acknowledge that our sample examined a targeted subset of a NZ university
320 population. These undergraduate students were all studying in the area of Health, Sport
321 and Human Performance, and limit the external validity of our findings to other
322 populations. It is reasonable to assume that these students may have additional knowledge

323 and a vested interest in maintaining a healthy lifestyle, potentially biasing their
324 ‘normative’ values. We purposefully excluded individuals with PFP as the goal was to
325 establish a normative baseline in individuals who not presented with pain. It is possible
326 that differences between Māori and NZ European patients with PFP exist, but requires
327 further research. In addition, the inter-rater reliability of measures was conducted 60-
328 minutes apart in a non-injured population. It is possible that familiarisation or learning
329 might have influenced the reliability outcomes, and worth highlighting that the reliability
330 of measures in non-injured populations does not ensure that tests are reliable in presence
331 of injury.

332

333

CONCLUSIONS

334

335 Overall, our study suggests that sex is an important factor worthy of further consideration
336 within the TIPP’s algorithm and subgrouping approaches, more so than ethnicity, although
337 it is noteworthy that Māori males showed tighter rectus femoris and Māori females
338 demonstrated greater patellar mobility. Based on this information, we recommend that a
339 lower strength threshold be applied for the classification of females into the “strong”
340 group for the allocation of individuals with PFP into subgroups. Overall, the different
341 tests used to classify subgroups within TIPP’s showed acceptable reliability, except for
342 the FPI. This clinical measure relies on subjective interpretations to a greater extent than
343 the others, and correspondingly was less reliable. This study provides direction to
344 improve TIPP’s, and warrants a sex-based stratified approach to PFP subgrouping. Ethnic
345 differences have been reported to exist in patients presenting with musculoskeletal pain,

346 including to the knee (Veerapen, Wigley, and Valkenburg 2007); therefore studies
347 examining ethnic differences within PFP cohorts should be further explored.

348

349

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355

356

DECLARATIONS OF INTEREST

357

358 None.

359

360

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