Feedback cues improve the alignment and technique of children performing ACL injury prevention exercises

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ABSTRACT

Objectives The appropriateness of neuromuscular training exercises across different age groups has not yet been investigated, particularly in younger children. The purpose of this study was to determine which neuromuscular training exercises can be performed with proper neutral alignment in various age groups.

Methods Seven exercises were selected for evaluation in children ranging from 8 to 17 years of age who were recruited from schools and youth sports organisations. Participants completed two trials of each exercise and were judged on maintaining neutral body alignment after receiving visual/verbal instruction on the first trial and feedback cues on the second trial. Three evaluators judged each exercise, which was deemed as correct when at least two evaluators agreed that neutral alignment was maintained. Comparisons were made across ages and between sex using the χ² test or Fisher’s exact test. The proportions of participants who performed the exercise correctly were also compared before and after feedback cues were provided.

Results A total of 360 participants were evaluated (8–11 years: 165, 54% female; 12–15 years: 136, 40% female; 16–17 years: 59, 53% female). There were no significant differences in performance across ages and sex for nearly all exercises. The majority of children were not able to complete the exercises with proper alignment. The use of feedback cues significantly increased the proportion of participants who correctly completed the exercise (p<0.001).

Conclusions These results demonstrate the importance of training coaches and physical education teachers to provide cues that reinforce proper technique during anterior cruciate ligament injury prevention exercises. Children should perform common neuromuscular training exercises with feedback on proper technique.

INTRODUCTION

Anterior cruciate ligament (ACL) rupture is one of the most common sports-related knee injuries, with an estimated 250 000 injuries per year in the USA.1 2 The standard surgical treatment is reconstruction of the ACL, but while clinical outcomes have improved over the years, there are still significant health consequences to ACL injuries.3 Although a majority of patients (81%–85%) return to some physical activity after ACL reconstruction (ACL-R), only 55%–65% return to their preinjury level of competition.4 5 There is also an increased risk of premature osteoarthritis and additional knee surgery, especially when the injury occurs at a young age.6 7 8 Due to the long-term consequences of ACL injuries, the ideal strategy is to avoid them by using prevention programmes that can decrease injury risk.

Several injury prevention programmes have been developed to decrease the occurrence of ACL injuries. A meta-analysis of overlapping meta-analyses reported that these programmes resulted in a 50% risk reduction in ACL injuries and an even higher reduction (67%) in non-contact ACL injuries in female athletes, who are at greater risk due to anatomical, biomechanical or physiological differences.9 10 There is ample evidence showing injury prevention programmes that incorporate balance, plyometric and strength training and that are effective for improving movement patterns and landing mechanics in older athletes have had limited success in younger athletes.11 12 In one study, high school participants improved their landing technique more than pre-high school participants.13 Another study evaluated a modified paediatric programme for children under age 12 that consisted of greater exercise variety and progressions, more feedback and reduced frequency.14 In contrast to the traditional programme that was developed for older athletes, participants using the paediatric version did not improve on balance and vertical jump height.15 Thus, younger children may require more attention and feedback when learning new tasks.16 It remains unclear whether the exercises are beyond the level of comprehension or perhaps not challenging enough for children in the younger age groups.15

Injury prevention programmes that have been effective for improving movement patterns and landing mechanics in older athletes have had limited success in younger athletes.16 17 In one study, high school participants improved their landing technique more than pre-high school participants.16 Another study evaluated a modified paediatric programme for children under age 12 that consisted of greater exercise variety and progressions, more feedback and reduced frequency.14 In contrast to the traditional programme that was developed for older athletes, participants using the paediatric version did not improve on balance and vertical jump height.15 Thus, younger children may require more specialised training in basic movement patterns. FIFA 11+Kids was one of the first programmes designed for youth populations (<13

What are the new findings

► Children should perform common neuromuscular training exercises with feedback on proper technique for anterior cruciate ligament injury prevention exercises.
► The results demonstrate the importance of training coaches and physical education teachers to provide cues that reinforce proper technique.
years of age) that takes into account physical maturity and age-
specific injury mechanisms. This programme consists of seven
different exercises across three progressive skill levels that focus
on spatial orientation, general stability and movement coordi-
nation and proper falling technique. A randomised controlled
trial found that after 4 weeks of participating in FIFA 11+Kids,
athletes showed improvements on jump performance, balance and
agility tests. The appropriateness of injury prevention exercises across
different age groups has not yet been investigated in adoles-
cent and preadolescent children. Exercises that are too difficult
will likely not be incorporated into warm-up routines, thereby
reducing adherence and negating their effect on preventing inju-
ries. While ability may vary within age groups, chronological
age is an important consideration for determining who plays on
the same team. Maintaining neutral alignment and using proper
technique may reduce the biomechanical risk factors that can
lead to injury. The purpose of this study was to determine which
neuromuscular training exercises can be performed correctly
(with proper alignment) by individuals of various age groups.
Our hypothesis is that athletes between the ages of 8–17 will
differ in their ability to perform the exercises with correct tech-
technique, with a progression in the appropriateness of exercise diffi-
culty as children get older. Having injury prevention programmes
that are appropriate for a particular age group may help facilitate
their adoption and maximise their impact on injury reduction.

METHODS

Participants

Written, informed parental consent and child assent were
obtained from every participant. Participants between the ages
of 8–17 years were enrolled from schools and youth sports
organisations in the greater New York City area. These chil-
dren were from physical education classes or recreational teams.
Participants were excluded if they were unable to understand the
visual/verbal instructions and cues provided by the investigators
or if they had a self-reported, existing musculoskeletal condition.

Procedures

The Sports Safety Program at our institution has developed
unique neuromdynamic warm-up programmes that coaches can
customise according to the skill/competition level and sport type.
Seven different exercises were selected from these programmes
for the participants ages 8–17 years, with increasing levels of
difficulty of the same exercise for older children. These exercises
were based on the five phases of the neuromdynamic warmup:
movement preparation, agility, lower-extremity strengthening,
plyometrics and core stability. Two exercises each were chosen
for the lower-extremity strengthening and plyometrics phases
since these exercises tend to be the most challenging. The ex-
cises performed in the 8–9 age group were the same as those in
the 10–11 age group. Similarly, the exercises performed in the
12–13 age group was the same as those in the 14–15 age group.
The 16–17 age group performed the most difficult exercises.
Thus, the results were categorised into three age groups: 8–11,

The participants performed each exercise twice. Prior to the
first attempt, the investigators used visual and verbal instruc-
tions when explaining how to perform the exercise. One person
provided instructions to small groups ranging from 5 to 10 chil-
dren depending on the number at each data collection session.
Verbal instructions were followed by a live demonstration of
each exercise: for example, ‘Run in a figure 8 motion through
these cones’ (Figure-8 Run) or ‘Begin in an athletic stance or
ready position and then shuffle feet laterally while repeatedly
raising arms overhead’ (Side Shuffle). On the second attempt,
the investigators provided visual and verbal cues that reinforced
correct movement technique: for example, ‘Keep your head in
line with your body’ or ‘Land softly and quietly’ or ‘Hips, knees,
and toes point straight ahead as you run’. Please see the online
supplemental appendix 1 for a script of the instructions and
cues for each exercise in each age group. After each attempt,
three experienced sports medicine practitioners (physical ther-
apists, athletic trainers and certified strength and conditioning
specialists), who faced the participants, determined if the partic-
ipant performed the exercise correctly by maintaining neutral
cervical-thoracic spine alignment, neutral lumbo-pelvic complex
alignment and neutral lower extremity alignment. For instance,
neutral alignment of the lower extremity is indicated by straight
alignment of the hip, knee and ankle. Exercise technique was
judged to be correct when at least two of the three evaluators
determined that neutral alignment in all three body regions was
maintained during the performance of each exercise.

Sample size calculation

Using an inequality test for one proportion with a null hypo-
thesis that 50% of participants are able to perform the exercise
correctly, we were able to achieve a power of 0.90 to detect an
alternative proportion of 80% at an alpha level of 0.05 with
28 subjects. Thus, the target enrolment for this study was 28
males and 28 females for all five age categories (8–9, 10–11,
12–13, 14–15, 16–17 years) for a total target enrolment of 280
participants.

Statistical analysis

Results for participants in the 8–11, 12–15 and 16–17 age
groups were analysed separately. For each exercise, compar-
isons between ages and sex were made using the χ² or Fisher-
’s exact test as appropriate. Proportions of participants who
could perform the exercise correctly before and after cues were
compared using a one-sample test of proportions. The kappa
statistic was used to measure inter-rater reliability among the
nine evaluators. Analyses were conducted using SAS V.9.4 (SAS,
Cary, North Carolina, USA).

RESULTS

A total of 360 participants were evaluated in this study: 71 in the
8–9 age category (55% female), 94 in the 10–11 age category
(54% female), 79 in the 12–13 age category (38% female), 57
in the 14–15 age category (37% female) and 59 in the 16–17
age category (53% female). There were no significant differ-
ences in exercise performance between participants ages 8–9
and 10–11 (online supplemental appendix 2) or ages 12–13 and
14–15 (online supplemental appendix 3). Similarly, there were
no significant differences between the proportions of males and
females who completed the exercises correctly when considering
both performance after instructions only and after instructions
plus cues for any of the age groups (tables 1–3).

For all exercises in every age group, there was a less than 50% 
success rate after the administration of instructions alone. The
use of feedback cues significantly increased the proportion of
participants who correctly completed the exercises (table 4).
However, there were some exercises in each age group for
which a majority of participants could not perform the exercise
with proper alignment even after cues were administered. In the
8–11 age group, the lowest proportions were seen for the scissor
jump, followed by the broad jump, lunge and double-leg squat. In the 12–15 age group, the lowest proportions were seen for the scissor jump, lunge, and broad jump. In the oldest 16–17 age group, the lowest proportions were found for the lunge and scissor jump at 49% and 48%, respectively. The kappa statistics for multiple evaluators were $k=0.31$ in the 8–11 age group, $k=0.42$ in the 12–15 age group and $k=0.31$ in the 16–17 age group, indicating fair to moderate agreement.

## DISCUSSION

In general, injury prevention programmes have used a ‘one size fits all’ approach and the same exercises have been recommended to athletes of all ages. There is a paucity of studies in younger athletes, particularly those under 12 years of age. The purpose of this study was to determine whether children 8–17 years of age can perform common neuromuscular training exercises correctly. For almost all exercises in this study, participants’ abilities for a particular age group may improve adherence to injury prevention programmes. Movement literacy is the basis for providing feedback on the movement quality. In the same study, the incorporation of verbal cues was one of several modifications made after the first season that led to a reduction in ACL injuries in the subsequent season. While the independent effect of providing cues is unclear in that study, we were able to measure the direct changes in proper alignment after cues were administered in our current study.

In a meta-regression, neuromuscular training programmes had the greatest injury risk reduction in female athletes who were in their early teenage years (<14) compared with older age groups. Another biomechanics study concluded that the FIFA 11+ programme was more effective in reducing known risk factors for ACL injury, namely knee valgus angle and moment on jump landings, in preadolescent (10–12 years) compared with adolescent female athletes. These findings highlight the importance of getting athletes of younger ages to learn correct movement patterns and the need for developing age-specific injury prevention programmes. Movement literacy is the basis for general physical development and motor learning, and it would be beneficial to lay the foundation in young athletes sooner than later. Furthermore, the availability of exercises that are suitable for a particular age group may improve adherence to injury prevention programmes.

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**Table 1** Proportion (%) of males and females ages 8–11 years who performed exercises correctly with proper alignment

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Males</th>
<th>Females</th>
<th>P value *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward/Backward Jog</td>
<td>32.0</td>
<td>35.6</td>
<td>0.74</td>
</tr>
<tr>
<td>Technique cues</td>
<td>69.3</td>
<td>73.3</td>
<td>0.61</td>
</tr>
<tr>
<td>Figure-8 Run (narrow)</td>
<td>48.0</td>
<td>50.0</td>
<td>0.88</td>
</tr>
<tr>
<td>Technique cues</td>
<td>82.7</td>
<td>77.8</td>
<td>0.56</td>
</tr>
<tr>
<td>Level 1 Lunge</td>
<td>2.7</td>
<td>7.8</td>
<td>0.18</td>
</tr>
<tr>
<td>Technique cues</td>
<td>32.0</td>
<td>23.3</td>
<td>0.23</td>
</tr>
<tr>
<td>Level 1 Double leg squat</td>
<td>21.3</td>
<td>16.7</td>
<td>0.55</td>
</tr>
<tr>
<td>Technique cues</td>
<td>49.3</td>
<td>41.1</td>
<td>0.35</td>
</tr>
<tr>
<td>Level 1 Broad jump</td>
<td>8.0</td>
<td>13.3</td>
<td>0.32</td>
</tr>
<tr>
<td>Technique cues</td>
<td>17.3</td>
<td>25.6</td>
<td>0.26</td>
</tr>
<tr>
<td>Level 1 Scissor jump</td>
<td>1.3</td>
<td>4.4</td>
<td>0.38</td>
</tr>
<tr>
<td>Technique cues</td>
<td>4.0</td>
<td>10.0</td>
<td>0.23</td>
</tr>
<tr>
<td>Level 1 Side plank</td>
<td>29.3</td>
<td>22.2</td>
<td>0.37</td>
</tr>
<tr>
<td>Technique cues</td>
<td>58.7</td>
<td>61.1</td>
<td>0.75</td>
</tr>
</tbody>
</table>

* $\chi^2$ p values represent the comparison between males and females.

**Table 2** Proportion (%) of males and females ages 12–15 years who performed exercises correctly with proper alignment

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Males</th>
<th>Females</th>
<th>P value *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Shuffle</td>
<td>42.4</td>
<td>45.1</td>
<td>0.76</td>
</tr>
<tr>
<td>Technique cues</td>
<td>78.8</td>
<td>80.4</td>
<td>0.83</td>
</tr>
<tr>
<td>Figure-8 Run (wide)</td>
<td>43.5</td>
<td>39.2</td>
<td>0.62</td>
</tr>
<tr>
<td>Technique cues</td>
<td>81.2</td>
<td>74.5</td>
<td>0.36</td>
</tr>
<tr>
<td>Level 2 Lunge</td>
<td>10.6</td>
<td>11.8</td>
<td>0.83</td>
</tr>
<tr>
<td>Technique cues</td>
<td>36.5</td>
<td>31.4</td>
<td>0.55</td>
</tr>
<tr>
<td>Level 2 Double leg squat</td>
<td>42.4</td>
<td>29.4</td>
<td>0.13</td>
</tr>
<tr>
<td>Technique cues</td>
<td>61.2</td>
<td>76.5</td>
<td>0.07</td>
</tr>
<tr>
<td>Level 2 Broad jump</td>
<td>12.9</td>
<td>11.8</td>
<td>0.84</td>
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<tr>
<td>Technique cues</td>
<td>45.9</td>
<td>45.1</td>
<td>0.93</td>
</tr>
<tr>
<td>Level 2 Scissor jump</td>
<td>10.6</td>
<td>5.9</td>
<td>0.35</td>
</tr>
<tr>
<td>Technique cues</td>
<td>31.8</td>
<td>15.7</td>
<td>0.04</td>
</tr>
<tr>
<td>Level 2 Side plank</td>
<td>55.3</td>
<td>31.4</td>
<td>0.007</td>
</tr>
<tr>
<td>Technique cues</td>
<td>83.5</td>
<td>72.6</td>
<td>0.13</td>
</tr>
</tbody>
</table>

* $\chi^2$ p values represent the comparison between males and females.

**Table 3** Proportion (%) of males and females ages 16–17 years who performed exercises correctly with proper alignment

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Males</th>
<th>Females</th>
<th>P value *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carioca</td>
<td>42.9</td>
<td>9.7</td>
<td>0.003</td>
</tr>
<tr>
<td>Technique cues</td>
<td>75.0</td>
<td>54.8</td>
<td>0.11</td>
</tr>
<tr>
<td>Forward/Backward Angled Run</td>
<td>28.6</td>
<td>25.8</td>
<td>0.81</td>
</tr>
<tr>
<td>Technique cues</td>
<td>82.1</td>
<td>71.0</td>
<td>0.31</td>
</tr>
<tr>
<td>Level 3 Lunge</td>
<td>3.6</td>
<td>6.5</td>
<td>0.62</td>
</tr>
<tr>
<td>Technique cues</td>
<td>53.6</td>
<td>45.2</td>
<td>0.52</td>
</tr>
<tr>
<td>Level 2 Double leg squat</td>
<td>42.9</td>
<td>54.8</td>
<td>0.36</td>
</tr>
<tr>
<td>Technique cues</td>
<td>71.4</td>
<td>83.9</td>
<td>0.25</td>
</tr>
<tr>
<td>Level 2 Broad jump</td>
<td>14.3</td>
<td>25.8</td>
<td>0.27</td>
</tr>
<tr>
<td>Technique cues</td>
<td>46.4</td>
<td>58.1</td>
<td>0.37</td>
</tr>
<tr>
<td>Level 3 Scissor jump</td>
<td>21.4</td>
<td>12.9</td>
<td>0.38</td>
</tr>
<tr>
<td>Technique cues</td>
<td>60.7</td>
<td>35.5</td>
<td>0.05</td>
</tr>
<tr>
<td>Level 3 Side plank</td>
<td>28.6</td>
<td>25.8</td>
<td>0.81</td>
</tr>
<tr>
<td>Technique cues</td>
<td>50.0</td>
<td>54.8</td>
<td>0.71</td>
</tr>
</tbody>
</table>

* $\chi^2$ p values represent the comparison between males and females.
enough, coaches can choose to increase the difficulty. One option. On the other hand, for exercises that are not challenging too difficult for their athletes, coaches can use a less challenging young athletes based on chronological age. For exercises that are considerations when designing injury prevention programmes for and the ability to correct movement deficiencies are important impact on reducing injuries.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Proportion (%) of participants ages 8–11, 12–15 and 16–17 who performed exercises correctly before and after administration of cues (all comparisons p&lt;0.001 unless otherwise noted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ages 8–11</td>
<td>Forward/Backward Jog</td>
</tr>
<tr>
<td></td>
<td>figure 8 Run (narrow)</td>
</tr>
<tr>
<td></td>
<td>Level 1 Lunge</td>
</tr>
<tr>
<td></td>
<td>Level 1 Double leg squat</td>
</tr>
<tr>
<td></td>
<td>Level 1 Broad jump</td>
</tr>
<tr>
<td></td>
<td>Level 1 Scissor jump*</td>
</tr>
<tr>
<td></td>
<td>Level 1 Side plank</td>
</tr>
<tr>
<td>Ages 12–15</td>
<td>Side shuffle</td>
</tr>
<tr>
<td></td>
<td>Figure 8 Run (wide)</td>
</tr>
<tr>
<td></td>
<td>Level 2 Lunge</td>
</tr>
<tr>
<td></td>
<td>Level 2 Double leg squat</td>
</tr>
<tr>
<td></td>
<td>Level 2 Broad jump</td>
</tr>
<tr>
<td></td>
<td>Level 2 Scissor jump</td>
</tr>
<tr>
<td></td>
<td>Level 2 Side plank</td>
</tr>
<tr>
<td>Ages 16–17</td>
<td>Carioca</td>
</tr>
<tr>
<td></td>
<td>Forward/Backward angled run</td>
</tr>
<tr>
<td></td>
<td>Level 3 Lunge</td>
</tr>
<tr>
<td></td>
<td>Level 2 Double leg squat</td>
</tr>
<tr>
<td></td>
<td>Level 2 Broad jump</td>
</tr>
<tr>
<td></td>
<td>Level 3 Scissor jump</td>
</tr>
<tr>
<td></td>
<td>Level 3 Side Plank</td>
</tr>
</tbody>
</table>

*χ² p=0.03.

Thus, the inclusion of developmentally appropriate exercises and the ability to correct movement deficiencies are important considerations when designing injury prevention programmes for young athletes based on chronological age. For exercises that are too difficult for their athletes, coaches can use a less challenging option. On the other hand, for exercises that are not challenging enough, coaches can choose to increase the difficulty. One study evaluating the Sportsmetrics programme in female soccer players failed to see significant changes in landing mechanics after 8 weeks compared with controls. The authors of this study hypothesised that their results may be due to the study population (mean age 10 years) who were unable to perform some of the exercises. In our study, the lunge and complex jumps such as the scissor and broad jump had the lowest proportions of correct alignment, even with the addition of feedback cues. Similarly, the investigators for the Sportsmetrics study removed the supine hamstring (bridge) when younger participants were physically unable to perform this exercise correctly. The length of the exercise as well as the intensity and duration of the injury prevention programme have also been mentioned as important considerations for maintaining proper form when performing an exercise.15

This study evaluated the ability to maintain neutral spinal and lower extremity alignment in young athletes with and without feedback cues, and the population that we used was a strength of the study. Children were recruited from physical education classes and recreational sports teams to increase the external validity of our findings. Recruiting from higher-level teams would likely result in a study sample with better movement competency and not provide the same type of normative data for the general youth population. The study also had several limitations. The agreement between evaluators was only moderate/fair and could be due to the large number of staff members that was required in order to conduct this study. Only certain exercises were evaluated, and the levels of difficulty for individual age groups were decided based on clinical judgement. For certain exercises, the language used in the instructions could be too complex for younger children to understand. Any improvement on the second trial may just be due to better understanding of how to perform the exercise. In addition, this study was cross-sectional in nature, as visual and verbal cues were only given once. It is possible that the use of cues over time will increase the proportion of children who complete the exercises with proper technique and alignment. Future research directions may include a longitudinal study on repeated feedback for long-term retention of correct movement quality, as well as a head-to-head comparison of injury prevention programmes that use instructions alone or both instructions plus cues and their impact on injury reduction.

**CONCLUSION**

Most neuromuscular training exercises had a less than 50% success rate for proper alignment in children 8–17 years of age. The use of verbal and visual cues significantly increased the proportions of participants who correctly completed the exercise. Children should perform common neuromuscular training exercises with feedback on proper technique.

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**Contributors** DIL was responsible for conceptualisation, data curation, methodology, statistical analysis, project administration, supervision and writing the manuscript. CB was responsible for data curation, methodology, project administration, and reviewing the manuscript. JJ was responsible for conceptualisation, data curation, methodology, project administration, supervision and reviewing the manuscript. BC was responsible for data curation, data curation, statistical analysis and reviewing the manuscript. NR was responsible for data curation, methodology, project administration, supervision and reviewing the manuscript. JK was responsible for conceptualisation, methodology, supervision and reviewing the manuscript. RGM was responsible for conceptualisation, methodology, supervision and reviewing the manuscript.

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