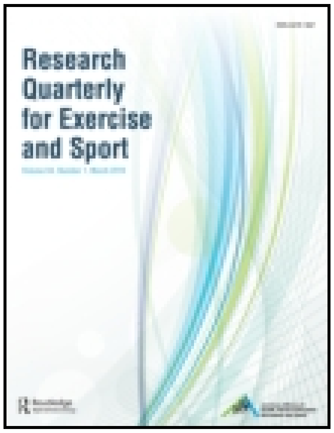




Research Quarterly for Exercise and Sport
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/urqe20

# Modifying Equipment in Early Skill Development: A Tennis Perspective

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Published online: 20 May 2014.

*Research Quarterly for Exercise and Sport*, *85*, 218–225, 2014

ISSN 0270-1367 print/ISSN 2168-3824 online
DOI: 10.1080/02701367.2014.893054

Routledge
Taylor & Francis Group



# Modifying Equipment in Early Skill Development: A Tennis Perspective

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**Purpose:** The International Tennis Federation recently launched a worldwide campaign advocating the use of equipment scaling for children learning to play tennis. The aim of this study was to investigate the influence that varying racquet sizes and ball compressions had on children's ability to play a forehand groundstroke. **Method:** This was a quantitative repeated-measures design experiment. Children were required to perform a forehand hitting task using each of 9 combinations of tennis racquets and balls (i.e., 3 racquet sizes × 3 ball compressions). Children's hitting performance was measured using a points system. The aim for the children was to score as many points as possible. Hitting technique was measured via video replay. **Results:** Hitting performance was best when the smallest racquet combined with the ball with the least compression was used. The ball with the least compression also promoted 2 technique benefits: swinging the racquet from low to high and striking the ball in front and to the side of the body. **Conclusions:** This study demonstrated the benefits for young children playing with scaled racquets and low-compression balls. The findings are discussed with regards to their relevance to theories of skill acquisition.

**Keywords:** children's sport, complex skill acquisition, physical education, talent development

In response to concerns over the physical demands imposed on children by adult constraints in sport, the potential to scale equipment and modify games to suit the physical capabilities of children was first mooted in the 1970s (Orlick & Botterill, 1975; Winter, 1980). Combined with an emphasis on competition and, in particular, winning, rather than skill development and fun, authorities felt that this accounted for the large proportion of children who dropped out of sport before reaching adolescence (Australian Sports Commission, 1991). Consequently, modified games and scaled equipment were advocated in school sports programs (e.g., Orlick & Botterill, 1975; Parkin, 1980; Winter, 1980).

In tennis, modified equipment, including light racquets, low-compression balls, reduced net heights, and smaller

Submitted April 10, 2013; accepted October 4, 2013.
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courts have all been in existence for several decades (Winter, 1980). However, these modifications have been introduced on the basis of rational argument rather than scientific evidence. A recent International Tennis Federation (ITF) campaign designed to promote children's tennis ("Play and Stay") endorsed the use of three different-sized racquets, balls, and courts (ITF, 2011), but there is a lack of objective research to substantiate this endorsement. According to the constraints-led approach to skill learning, the task, the environment, and the performer interact to influence motor performance (Davids, Button, & Bennett, 2008; Newell, 1986). Thus, by modifying equipment, the task constraints are altered, which subsequently can confine a learner's movement pattern to expedite skill acquisition. For example, playing tennis with a ball that bounces too high constrains a child's movements to only striking the ball above their head. Alternatively, using a ball that bounces lower allows children to strike the ball at a more comfortable height and thereby increases their likelihood of developing suitable movement patterns to perform a tennis groundstroke.

The extant research examining task/equipment scaling in tennis has demonstrated the potential benefits for children using lighter racquets on smaller courts with lower-compression balls (e.g., Elliott, 1981; Farrow & Reid, 2010a; Groppel, 1977; Hammond & Smith, 2006). A lower-compression ball moves slower through the air and bounces lower than a standard ball, which appears to allow learners to strike the ball with better technique and with more power without the fear of the ball traveling out of court (Farrow & Reid, 2010a; Hammond & Smith, 2006). Some research has also examined the influence of racquet size on skill performance, and it appears that scaling a racquet to a child's size promotes better hitting performance (Elliott, 1981; Groppel, 1977). Specifically, it has been reported that scaled racquets encourage greater horizontal velocity and less vertical movement compared with larger racquets (Groppel, 1977). However, research examining equipment scaling in tennis has been limited by a failure in some cases to control for the influences of coaching or to match control and experimental groups for age and skill level (e.g., Hammond & Smith, 2006). Consequently, empirical evidence is needed to guide task and equipment scaling for beginners learning to play tennis and, furthermore, to inform the progression of scaling as skill develops—as Farrow and Reid (2010b) explained, "the challenge now lies in establishing some practical scaling recommendations that help to foster a love for the game and expedite skill acquisition" (p. 232).

The aim of this study was, therefore, to examine the influence of different combinations of racquet size ($n = 3$) and ball compression ($n = 3$) on young children playing tennis. We were specifically interested in three variables: hitting performance, hitting technique, and children's preference for racquet and ball. The racquet sizes ranged from smaller in length to larger, while the compression of the balls varied from 25% to 100% compression relative to the standard tennis ball (ITF, 2013). Based on previous research (Elliott, 1981; Farrow & Reid, 2010a, 2010b, we hypothesized that children would hit most accurately and with better technique when using the most scaled racquet and the lowest-compression ball. We also predicted that children would prefer playing with the scaled equipment compared with the full-size (adult) equipment (Farrow & Reid, 2010a). Additionally, we expected that children's height would moderate the influence of varying racquet/ball combinations, with taller children finding it easier to wield the larger racquets and to cope with the higher-compression, higher-bouncing balls.

## METHODS

### Participants

Eighty children aged 6 to 8 years old (boys, $n = 45$, $M_{age} = 7.7 \pm 0.9$ years; girls, $n = 35$, $M_{age} = 7.8 \pm 0.8$ years) with limited to no experience playing tennis participated in the study. The height of all children was measured prior to participation (boys, $M = 130.1 \pm 7.2$ cm; girls, $M = 128.6 \pm 7.6$ cm). Written voluntary consent was provided by all of the children and their parents and/or guardian. A university human research ethics committee and the relevant Department of Early Childhood Development approved the study.

### Procedure

Children performed a forehand hitting task using each of the nine combinations of tennis racquets and balls (i.e., three sizes × three compressions). The tennis racquets were all standard Wilson racquets that varied in length: 48.3 cm (weight = 200 g, grip circumference = 9.2 cm), 58.4 cm (weight = 220 g, grip circumference = 9.2 cm), and 68.6 cm (weight = 249 g, grip circumference = 10.5 cm). For the purpose of this study, the racquets will be referred to as small (48.3 cm), medium (58.4 cm), and large (68.6 cm). The balls were also manufactured by Wilson and included a standard-compression *yellow* ball (compression = 100%, diameter = 65.4 cm, weight = 56.0 g, rebound height = 139.0 cm), a low-compression *green* ball (compression = 75%, diameter = 65.4 cm, weight = 50.0 g, rebound height = 121.0 cm), and a very low-compression *red* ball (compression = 25%, diameter = 71.6 cm, weight = 44.0 g, rebound height = 100.0 cm). The ball rebound heights when dropped from 2.54 m were consistent with the ITF's recommendations (ITF, 2013). The hitting task was performed on a scaled court (size: 8 m × 4 m) with an asphalt surface and a net that was 0.8 m high, as recommended by the ITF for children of this age and skill level. Two digital video cameras were used to allow for analysis of hitting technique and hitting performance via video replay.

The researcher threw the ball underarm so that it landed in a target area (see Figure 1) on the child's forehand side. If the ball did not land in the target area, the throw was repeated. To ensure that throws were of equivalent difficulty in the nine racquet/ball combinations, the time taken from ball release to landing was calculated for each shot of a random subset of 20 participants. Cronbach's alpha for the nine conditions was .93, suggesting that throws were consistent. We asked children to play forehand shots only and to score as many points as possible by making contact with the ball (1 point) and then landing the ball on specific zones on the court. Four points were awarded for balls that landed in the deepest zone of the court (regulation and attainment of depth represents a fundamental tactic in tennis), whereas shots landing in zones that were less deep were awarded 3 points, 2 points, or 1 point, incrementally (see Figure 1). Two bonus points were also awarded if the ball was hit over the net but under a 2-m frame (see Figure 1). Seven shots were performed with each combination of racquet and ball. Children were only allowed to have one hand on the racquet when hitting the ball, and all were required to hold the racquet at the same position (relative to the racquet size) to ensure that they did not artificially reduce the length. Order of presentation of each racquet/ball combination was counterbalanced using a Latin square design. A sample of 20 participants performed the hitting task again after 1 week to assess test–retest reliability. Intraclass correlation coefficients (ICCs) indicate moderate-to-high reliability for all combinations. The ICC value was between .75 and .90 for five of the nine combinations, while four combinations had ICC values between .64 and .75. These four combinations were the red ball/large racquet, green ball/small racquet, green ball/ medium racquet, and yellow ball/small racquet. On completion of the experiment, we asked children which racquet and ball they most preferred to use.

Hitting performance (number of points accumulated for each racquet/ball combination) and hitting technique were measured via video replay. We did not inform children that their hitting technique was being assessed. An independent rater assessed children's hitting technique using Tennis Australia's technical fundamentals checklist (Tennis Australia, 2012). The checklist is composed of six technical points: (a) grip, an eastern forehand grip to a semi-western forehand grip was required; (b) circular swing, a circular-like motion had to be created in the backswing with the racquet; (c) low-to-high swing, the racquet had to be swung from low to high during the forward swing but with an arc

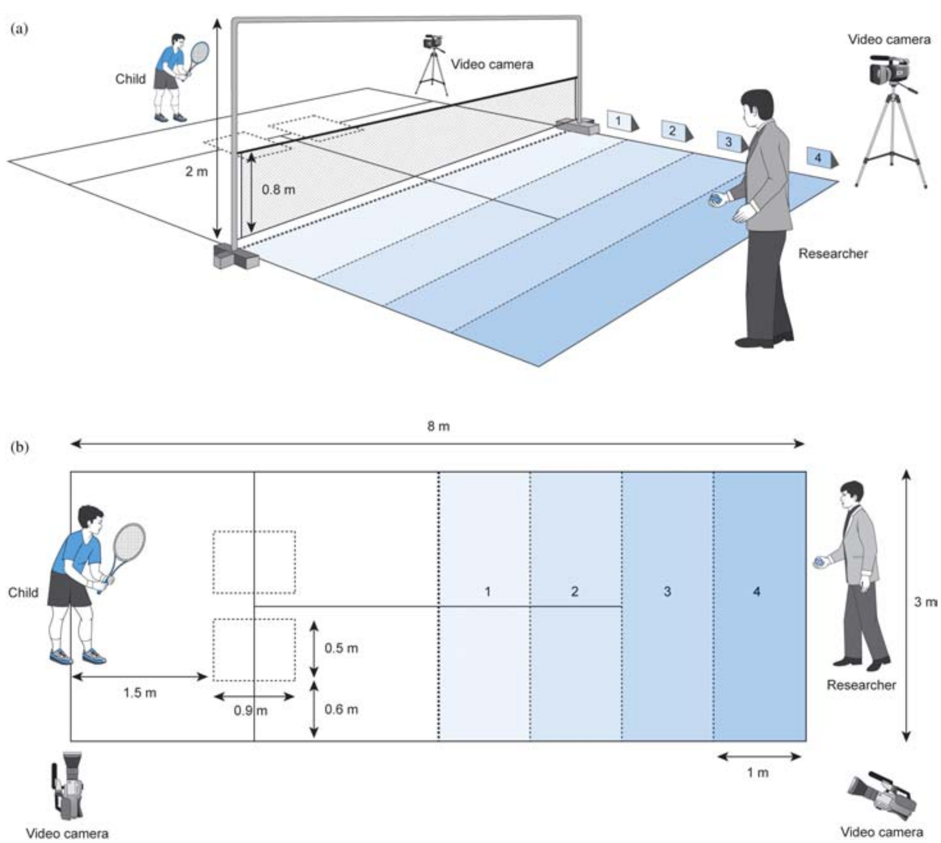


FIGURE 1 The court setup (a) and court dimensions (b). (Color figure available online.)

that was more horizontal than vertical; (d) step forward, children were expected to step forward into the shot with the opposite leg to their hitting hand; (e) impact, the ball needed to be struck in front and to the side of the body; and (f) follow-through, the follow-through needed to be considered a natural extension of the swing (i.e., extension and flexion of the elbow). For each trial, children were given a score of 1 or 0 depending on whether their movements corresponded with the checklist. The hitting technique of 28 randomly selected participants was reanalyzed by a second independent rater for reliability purposes. To assess reliability, the scores for each technique variable were tallied across the seven conditions to allow for an assessment of each variable individually. ICCs indicate moderate-to-high correlations for each technique variable (grip, ICC = .91, $p < .01$; circular swing, ICC = .90, $p < .01$; low-to-high swing, ICC = .85, $p < .01$; step forward, ICC = .81, $p < .01$; impact, ICC = .83, $p < .01$; follow-through, ICC = .84, $p < .01$).

## Data Analysis

Preliminary analysis indicated that none of the dependent variables interacted with gender, so boys and girls were collapsed. Repeated-measures analyses of covariance, using height as a covariate, were used to assess differences in hitting performance and hitting technique in each of the nine racquet/ball combinations, respectively. Greenhouse-Geisser adjustments were used to correct for violations of the sphericity assumption where appropriate. Where main effects were present, post-hoc comparisons were conducted using the Bonferroni method to adjust the $p$ values (the adjusted $p$ values are reported in the article). Chi-square tests were used to assess differences between the children's preferred racquet and ball selections. For all tests, statistical significance was set at $p < .05$. Effects between conditions for all variables were also reported. Partial eta square ($\eta_p^2$) was reported as the effect size for main effects, while Cohen's $d$ was used to report the standardized mean difference between specific conditions. Magnitudes of effects were interpreted using Cohen's (1988, 1992) thresholds for partial eta square (< .01, trivial; .01–.06, small; .06–.14, moderate; > .14, large) and Cohen's $d$ (< 0.2, trivial; 0.2–0.5, small; 0.5–0.8, moderate; > 0.8, large). Cramer's $V$ was reported as the effect size for the chi-square test.

## RESULTS

A main effect for hitting performance, $F(8, 624) = 6.63$, $p < .001$, $\eta_p^2 = .08$, was found among the nine racquet/ball combinations. Height, the covariate, did not have a significant influence on the results. The most scaled combination (small racquet/red ball) produced significantly greater hitting performance compared with all other racquet/ball combinations involving the yellow ball (standard adult ball). Overall, it appeared that the very low-compression red ball had the greatest positive influence on hitting performance, especially when combined with the small or medium racquets (see Figure 2). The low-compression green ball also had a positive influence on hitting

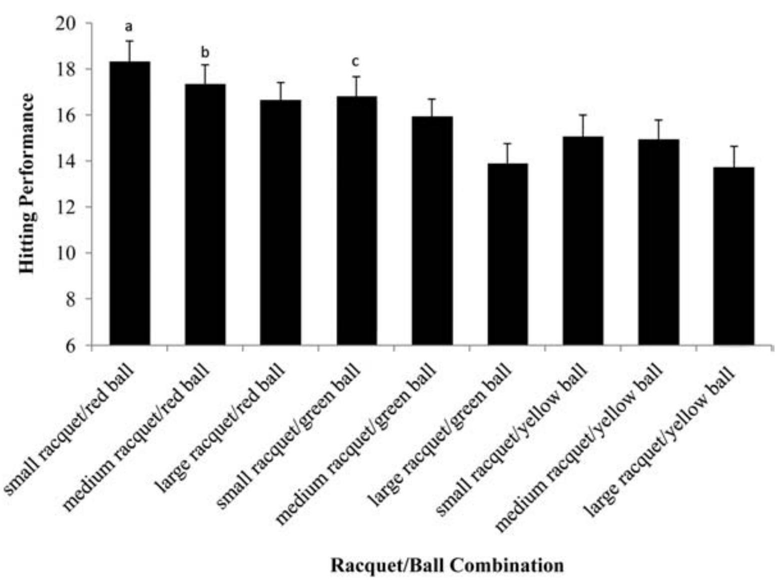


FIGURE 2 The mean points scored (hitting performance) for the nine racquet/ball combinations; "a" represents a significantly higher score than the large racquet/green ball combination ($d = 0.64$), the large racquet/yellow ball combination ($d = 0.60$), the medium racquet/yellow ball combination ($d = 0.40$), and the small racquet/yellow ball combination ($d = 0.38$); "b" represents a significantly higher score than the large racquet/green ball combination ($d = 0.48$) and the large racquet/yellow ball combination ($d = 0.46$); "c" also represents a significantly higher score than the large racquet/green ball combination ($d = 0.37$) and the large racquet/yellow ball combination ($d = 0.38$). Statistical significance level was $p < .05$. Error bars represent the standard error.

performance, but only when combined with a small racquet. It was evident that the large racquet and the standard yellow ball had a deleterious effect on hitting performance.

With regard to hitting technique in the nine combinations, main effects were found for low-to-high swing, $F(6.0, 398.7) = 24.13$, $p < .001$, $\eta_p^2 = .27$, impact, $F(6.5, 429.7) = 16.15$, $p < .001$, $\eta_p^2 = .20$, and step, $F(6.4, 416.9) = 2.97$, $p = .006$, $\eta_p^2 = .04$. Post-hoc analysis showed that there were significantly more low-to-high swings when the low-compression red ball was used, regardless of the racquet size, compared with every other racquet/ball combination (see Figure 3). Similarly, when the red ball was used, children made impact with the ball in front and to the side of their body more often than when the yellow ball was used, regardless of racquet size. It was also found that when the green ball was used in combination with either of the two scaled racquets (small or medium), children made correct impact with the ball more often than when any combination involving the yellow ball was used or when the large racquet/green ball combination was used

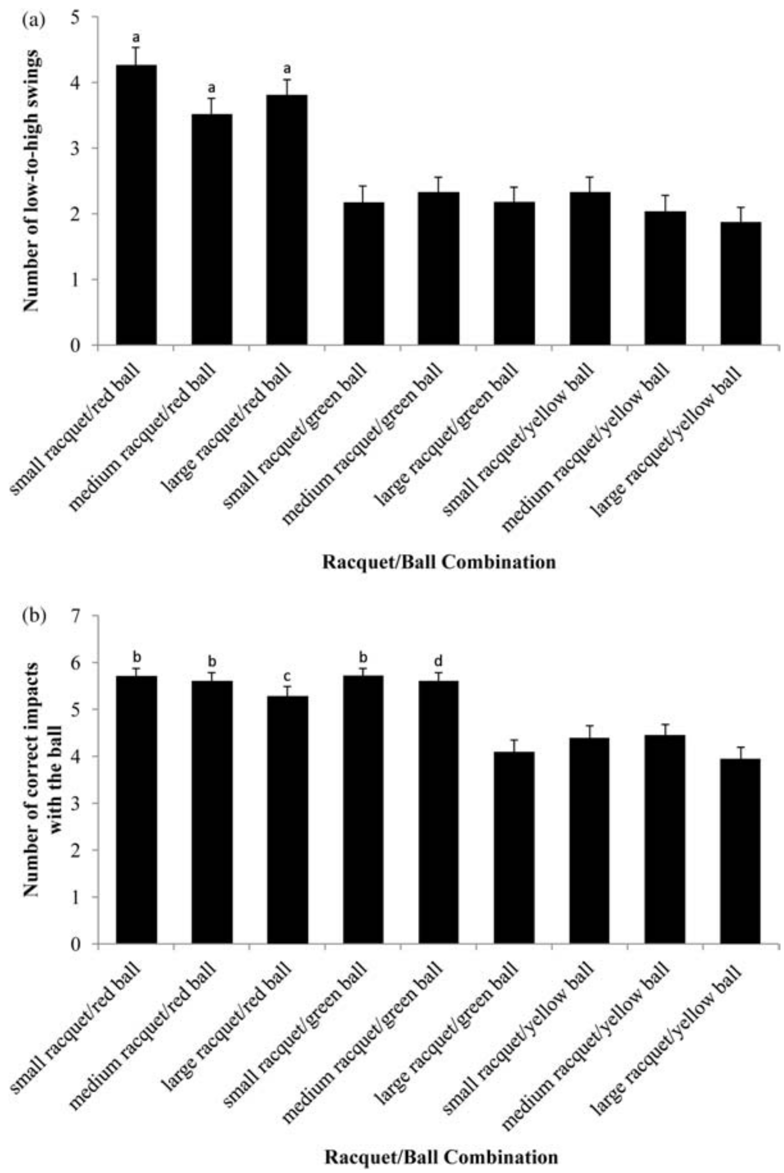


FIGURE 3 The mean number of occurrences of (a) low-to-high swings and (b) impacts with the ball in front and to the side of the body. "a" represents significantly more low-to-high swings than all combinations involving the green ball (d ranged from 0.62 to 0.90) and the yellow ball (d ranged from 0.66 to 0.96); "b" represents significantly more correct impacts with the ball than all combinations involving the yellow ball and the large racquet/green ball combination (d ranged from 0.59 to 0.85); "c" represents significantly more correct impacts than the large racquet/green ball combination ($d = 0.51$), small racquet/yellow ball combination ($d = 0.43$), and large racquet/yellow ball combination ($d = 0.62$); "d" represents significantly more correct impacts than the large racquet/green ball combination ($d = 0.47$) and large racquet/yellow ball combination ($d = 0.59$). Statistical significance level was $p < .05$. Error bars represent the standard error.

(see Figure 3). For step, post-hoc analysis revealed only one difference among the nine conditions, with stepping forward occurring significantly more often for the small racquet/red ball combination than the large racquet/green ball combination ($d = 0.49$, $p = .007$). There was no main effect for grip, $F(4.7, 316.4) = 2.04$, $p = .07$, $\eta_p^2 = .03$, with most children adopting the correct grip for all combinations. Likewise, there was no main effect for follow-through, $F(5.9, 390.2) = 1.34$, $p = .22$, $\eta_p^2 = .02$, with children adopting a follow-through on approximately 50% of the trials for all combinations. A circular swing was displayed by only 17 children, for whom no main effect was evident across combinations, $F(4.5, 62.6) = 1.53$, $p = .20$, $\eta_p^2 = .09$. Clearly, a circular swing is not a common attribute for children with limited tennis experience.

Chi-square tests revealed a main effect for preferred racquet, $X^2(2, N = 76) = 7.05$, $p = .03$, Cramer's $V = .22$, with children preferring to use the medium racquet ($n = 36$) more than the small ($n = 18$) and large ($n = 22$) racquets. No main effect for ball preference was found, $X^2(2, N = 76) = 3.50$, $p = .17$, Cramer's $V = .15$, although more children preferred the red ball ($n = 33$) than the green ($n = 22$) and yellow ($n = 21$) balls.

## DISCUSSION

The aim of the study was to examine the influence of equipment scaling in tennis for children aged 6 to 8 years old. Performance was better when children used scaled equipment rather than unscaled adult equipment. Performance was best when the modified red ball was used, and this ball had 75% less compression than the standard yellow ball and was 10% bigger. Consequently it bounced much lower (rebound height was 39 cm less than the standard ball). Children's height did not influence performance among the varying racquet/ball combinations, which refuted our hypothesis that taller children would find it easier to swing the larger racquets and cope with the higher-bouncing balls. Additionally, the majority of children in the current study preferred using the medium-sized racquet. Although this racquet was not the smallest, this finding still supports Farrow and Reid's (2010a) finding that young children learning to play tennis had more fun playing with scaled equipment in a modified space. The results have important practical implications for parents, teachers, and coaches alike when deciding what sports equipment to provide for children.

Two important improvements in technique resulted when the softest (red) ball was used. First, children swung the racquet from low to high more often, regardless of the racquet size that they used. Second, the red ball was struck in front and to the side of the body more often than when the yellow ball was used. Research suggests that both of these qualities are critical for the development of top-spin when performing a forehand shot (Elliott & Marsh, 1989; Knudson, 2006; Takahashi, Elliott, & Noffal, 1996). Children also struck the ball in front and to the side of their body when the low-compression green ball was used, but only when in combination with the small or medium racquet (not with the adult-sized large racquet). Tennis coaching manuals suggest that children should not play with balls that either bounce above their strike zone or travel too fast, as this may impair the biomechanical development of their strokes (Barrel, 2008), but it appears that it may be the interaction between racquet and ball that most affects biomechanical development. In essence, the children were able to develop a functional movement solution as a result of self-organization under the interacting task constraints. Importantly, this movement solution was also consistent with tennis coaching literature in terms of preferred swing patterns. The findings of the current study are consistent with literature that supports equipment and task scaling in other sports, such as basketball (Arias, Argudo, & Alonso, 2012) and cricket (Elliott, Plunkett, & Alderson, 2005).

From a theoretical perspective, modifying equipment has many potential benefits for children's skill acquisition. For instance, altering task constraints (i.e., scaling equipment) to allow the skill to be performed with greater ease may encourage learners to focus on key perceptual variables, which facilitates the development of coordinated and controlled movement patterns (Davids et al., 2008). Similarly, the use of a lighter racquet and a slower-moving ball may allow children to focus on the tactics of where to hit the next shot rather than focusing internally on their movements (Chow et al., 2007). Proponents of the constraints-led approach argue that modifying the task allows children to search for new solutions by exploring the practice environment, which ultimately facilitates unconscious processes of learning (e.g., Renshaw, 2010). It is unclear whether this is the case, as proponents of implicit motor-learning theory (e.g., Masters & Poolton, 2012) suggest that "searching for new solutions" may sometimes result in hypothesis testing, which is likely to cause conscious aggregation of explicit knowledge about performance. Clarification of this issue requires further investigation.

Implicit motor-learning theory can also be used as a framework to support the use of modified equipment. Implicit motor learning involves the acquisition of motor skills without conscious access to the information or knowledge that underlies their performance (Masters, 1992; for a recent review of implicit motor learning, see Masters & Poolton, 2012). Skills learned implicitly have been shown to be resistant to psychological stress (e.g., Liao & Masters, 2001), physiological fatigue (e.g., Masters, Poolton, & Maxwell, 2008), and cognitively demanding secondary tasks (e.g., Maxwell, Masters, & Eves, 2003). Research in both adults and children has shown that practicing skills with few errors reduces hypothesis testing during the motor-learning process, which limits the likelihood that performers become aware of knowledge underlying their performance (e.g., Capio, Poolton, Sit, Holmstrom, & Masters, 2013; Maxwell, Masters, Kerr, & Weedon, 2001; Poolton, Masters, & Maxwell, 2005). Hence, the skills are learned implicitly. Learners commit errors regardless of the equipment that they use (as demonstrated by hitting performance in the current study), but simplifying the task may at least reduce conscious processing during performance. Consequently, it is plausible that children playing with modified equipment experience implicit motor-learning benefits.

The finding that children preferred using the medium-sized racquet relates to recent work investigating children's attunement to "affordances" (i.e., opportunities for action).[1] Beak, Davids, and Bennett (2000) found that children were sensitive to changes in racquet characteristics and preferred to use racquets with lower moment of inertia, although only when their vision was occluded. This may explain why the medium racquet was preferred over the smallest racquet in the current study—the smallest racquet may have been perceived as "beginner" equipment by children who preferred to mimic their idols on television (Beak et al., 2000). In support of the concept that children are attuned to affordances when wielding a tennis racquet, it was observed that 50% of children tried to use a double-handed grip (despite instructions not to) when using the large (68.6 cm) racquet during the experiment. Comparatively, only two children used the double-handed grip with the medium (58.4 cm) racquet, and none needed to use it with the small (48.3 cm) racquet. Hence, many children found the adult-sized racquet too difficult to swing with one hand and appeared to be aware of the affordances provided when using two hands. This observation is consistent with previous research examining the use of scaled racquets for children learning to play tennis (Elliott, 1981; Groppel, 1977).

In summary, this study demonstrated benefits for young children playing with scaled racquets and low-compression balls. Specifically, the low-compression red ball provided the most benefits—both for hitting performance and technique. The study also provided further insight into the preferences of young children and added support to previous literature that children prefer playing with equipment scaled relative to adult equipment (e.g., Farrow & Reid, 2010a). Future research needs to examine the influence that modified equipment has on learning and distinguish the predominant nature of the learning (implicit or explicit). The results add support to a small but growing literature base that examines the benefits of equipment scaling for children. We therefore argue that children's use of developmentally appropriate equipment may result in the acquisition of motor patterns that will allow them more success as adult players.

[1]The term "affordance" is used in the ecological approach to motor learning. Theorists argue that everything is an affordance, but some things have a greater affordance than others, depending on the task, the individual, and the environment. For example, a small racquet would likely provide greater affordance than a large racquet for a child playing tennis, but the opposite would probably be found for an adult (for a review of the ecological approach to skill acquisition, see Handford, Davids, Bennett, & Button, 1997).

## WHAT DOES THIS ARTICLE ADD?

Although the use of modified equipment for children has been advocated for several decades, it is still unclear which modifications best suit the varying ages and skill levels of junior tennis payers. The current study increases our understanding of this issue with the results supporting the ITF's recommendation that children aged 6 to 8 years old should use both low-compression red balls and 48.3-cm to 58.4-cm racquets. Our study also supports the alternative recommendation that children should select their own equipment given that they appear to be attuned to the "affordances" provided by the equipment (Beak et al., 2000; Headrick, Renshaw, Pinder, & Davids, 2012). Nonetheless, physical education teachers and tennis coaches should be aware of the performance benefits for young children using equipment that has been scaled to suit the children's physical size. Similarly, parents should be aware of the benefits of modified equipment when purchasing equipment for their child. And importantly, tennis clubs and associations should take heed of the results and continue to encourage the "modified approach" in their junior programs.

## ACKNOWLEDGMENTS

The authors would like to acknowledge Tennis Australia and the International Tennis Federation for their assistance in the project. Our thanks also extend to the Department of Education and Early Childhood Development in Victoria for their Support, and to Eltham Primary School and St. Joan of Arc Primary School in Melbourne, Victoria, for their contributions to the study.

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