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Structured Functional Training Enhances Motor Skill Acquisition and Functional Health in Adolescent Athletes: A Randomized Controlled Trial

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ABSTRACT

Adolescence is one of the stages of development where rapid neuromuscular growth and increased neuroplasticity occur. There have been less studies that examine the role of integrative training methods on the efficiency of motor learning and functional adaptation specifically. In the present study, the impact of a systematic functional training program on motor skill-related performance and functional health indicators in young volleyball players were examined. It has been a randomized controlled trial involving 52 male adolescent athletes aged 13 + 2 years over a 12-week training period who were randomly assigned to the functional training group (FTG n = 26) and traditional resistance training group (TRTG n = 26). The functional training program involved multi-joint and task-oriented exercises. Both FTG (P = 0.025; d = 0.74) and AP-R (P = 0.034; d = 0.69) increased significantly indicating better vertical coordination and intermuscular synchronism. Agility performance had moderate effect size (d = 0.58) meaning that it did not statistically differ (P = 0.075). The TRTG experienced excellent increase in agility (P = 0.028, d = –0.72) but no change in vertical performance. Comparison of post-intervention measurements across groups demonstrated no significant differences (all P > 0.05). These findings suggest that training structure is a key element in predicting the results of motor learning and provide a foundation to consider other time-based training models that aim at optimizing the development of skills and functional capabilities in the youth population.

Keywords: Motor skill acquisition, Functional health, Adolescent athletes, Neuromuscular adaptation, Training structure, Randomized controlled trial

INTRODUCTION

Youthfulness is a significant physiological and psychological turning point that has been acknowledged as a sensitive time of motor development and brain reorganization (Aoki et al., 2017; Lloyd et al., 2015). In the pubertal growth spurt, the Central Nervous System (CNS) has increased synaptic plasticity and environmental responsiveness because of changing hormonal profiles, particularly higher levels of growth hormone and testosterone, and increased rate of neural myelination (Tumkur Anil Kumar et al., 2021). The

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biological window has unprecedented potential to improve the quality of neuromuscular control but it also has its own peculiarities. The fast increase in biomechanical levers (limb lengths) can be too quick relative to the CNS recalibration of motor programs, which commonly causes a temporary state of adolescent awkwardness or motor discoordination. The structure, intensity and specificity of training interventions have a strong and possibly long-lasting effect on long term functional outcomes and athletic trajectories against this volatile developmental backdrop.

Physical performance improvement is also one of the major goals in the field of youth athletic development. Resistance Training (TRT) has traditionally been considered as the gold standard to develop muscle strength, power, and overall physical literacy (Behm et al., 2008; Faigenbaum and Myer, 2010). TRT can effectively promote muscle fibre hypertrophy and enhance motor unit recruitment with external loads being used in a controlled setting. However, once examined using the Motor Learning Theory perspective, the shortcomings of TRT become more obvious. TRT is mostly focused on individual muscles and linear, mono-planar patterns of movement, usually restricted to the sagittal plane. These very structured and repeated stimulus are likely to cause what scientists refer to as a transfer deficit. Although an athlete may exhibit substantial strength improvements in a laboratory or gym environment, these improvements do not always carry over to the higher degrees of freedom (DoF), non-linear, and chaotic requirements of competitive sport that demand smooth coordination between several joints and planes of movement.

On the other hand, Functional Training (FT) has become a holistic paradigm shifting the emphasis on muscles to movement patterns. FT focuses on kinetic chain integration, core stabilization, and multi-planar neuromuscular coordination. By adding exercises which are representative of real-life athletic movements, such as acceleration, deceleration, and rotational power, FT was developed to improve the Transfer of Training (ToT) effect (Crawford et al., 2018; Pereira et al., 2025; Xiao et al., 2025). In terms of motor learning, successful skill acquisition goes beyond raw muscular strength; it requires sophisticated timing, anticipatory postural modifications, and flexibility. As per the theory of dynamic systems, motor control comes out as a result of the interaction among the organism, the environment, and the task. FT will help achieve this through the introduction of strategic task variation and stochastic perturbation. These challenges prompt the adolescent CNS to search in greater state-of-space and find best, strong motor solutions, hence enhance the economy of movement and decrease the chance of injury (Lloyd et al., 2015; Wan et al., 2025).

Although the theoretical interconnection between functional training and motor learning principles can be very convincing, there is still a significant lack of empirical studies on their interactions in adolescent groups, although recent systematic reviews have shown that functional training has a positive effect on adolescent physical fitness (Liu et al., 2025). The majority of available literature is based on physiological indicators (e.g., maximal strength) as opposed to neural control strategies and movement quality. This paper will thus seek to address this gap by reinvestigating the impact of training in the context of motor learning, exploring how functional interventions promote neural adaptation and promote a smooth transition of physical capabilities to sporting performance in young athletes.

The conceptual synthesis of these parts, including adolescent neural plasticity and TRT and FT divergent pathways, is represented by the conceptual framework shown in Figure 1. The model, as shown, explains how functional interventions can make use of the CNS flexibility of the vulnerable period to overcome the transfer deficit of conventional approaches, finally leading to the optimization of motor learning efficiency via particular mechanistic mechanisms such as improved inter-muscular coordination or better proprioception.

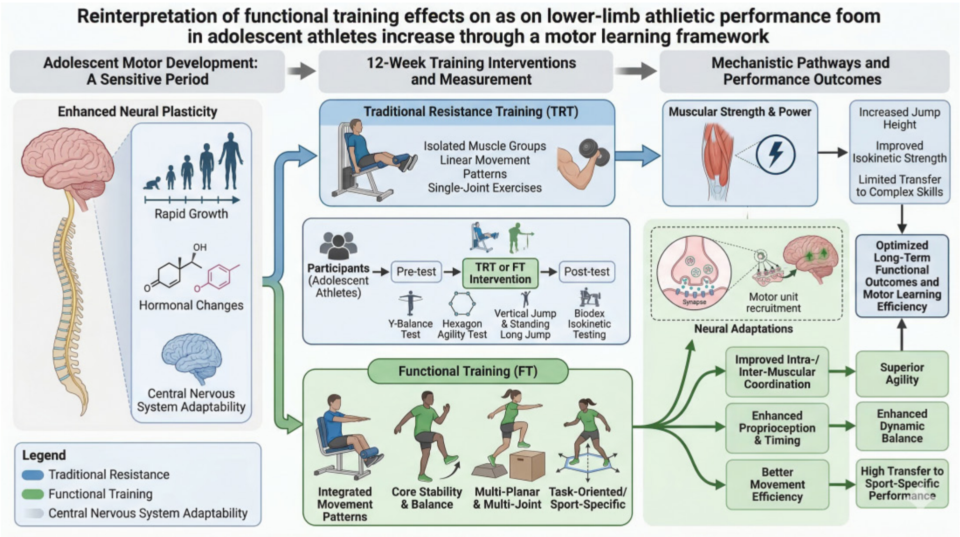

Figure 1: Functional training framework for motor learning in adolescent athletes.

METHOD

A randomized controlled trial approach was used to determine the impact of structured functional training on motor skills learning and functional health among adolescent athletes. Fifty-two male adolescent volleyball players (13 +2) who had at least two years of formal training experience were selected and randomly divided into functional training group (FTG, n = 26), or traditional resistance training group (TRTG, n = 26).

The intervention was 12 weeks long, and each group attended three training sessions per week. Every session had standard warm-up phase, main training phase and cool-down period, which provided safety and uniformity among participants (Fernandez-Fernandez et al., 2020). In the course of the intervention, 12 participants dropped out because of causes unrelated to the training process, leaving 40 participants (20 per group) who completed the study protocol.

The functional training programme was developed according to the concept of motor learning and neuromuscular adaptation (Granacher et al., 2018; Lloyd et al., 2015). It focused on multi-joint and multi-planar motions that were quite similar to sport-specific actions (Pereira et al., 2025; Xiao et al., 2025). The exercises were dynamic in nature with regards to balance, core stability and coordinated movements of both upper and lower extremities. Also, the intervention included task variability and increasing complexity which was meant to promote sensorimotor integration and adaptive motor learning.

Alternatively, the conventional resistance training group did conventional strength training exercises such as squats, deadlifts, and lower-limb resistance motions. The main aim of these exercises was to enhance muscular strength by means of controlled repetitive and linear movement patterns.

Every participant was evaluated before and after the intervention in standard conditions. The outcome variables were standing reach height, approach reach height, agility (half-meter square test), standing long jump, sprint speed, and endurance performance. All the tests were repeated two times and the highest value was used in the analysis.

The statistical analysis was done with the help of the SPSS software. Data was presented in form of means plus or minus standard deviations (Mean +/SD). Within-group differences were tested using paired-sample t-tests, whereas between-group comparisons were tested by independent-sample t-tests. The statistical significance was determined at $P < 0.05$.

RESULTS

After the 12 weeks intervention, all groups have demonstrated improvement in a number of performance variables; nonetheless, the adaptations occurred in different ways in each group.

The functional training group showed important changes in the measure of standing reach height ($P = 0.025$; $d = 0.74$) and approach reach height ($P = 0.034$; $d = 0.69$), suggesting better vertical coordination and intermuscular synchronization (Granacher et al., 2018; Liao et al., 2021).

The functional training group saw an improvement in their agility performance with a moderate effect size ($d = 0.58$) though the difference was not statistically significant ($P = 0.075$). It indicates that functional training can be used to improve movement efficiency and coordination.

Conversely, the conventional resistance training group showed a statistically significant change in agility ($P = 0.028$; $d = -0.72$) but there was no statistically significant change in the vertical performance measures.

The comparison of groups was conducted after the intervention and it was found that there were no statistically significant differences between the groups on all variables (all $P > 0.05$) but there were different adaptation patterns of the two training modalities.

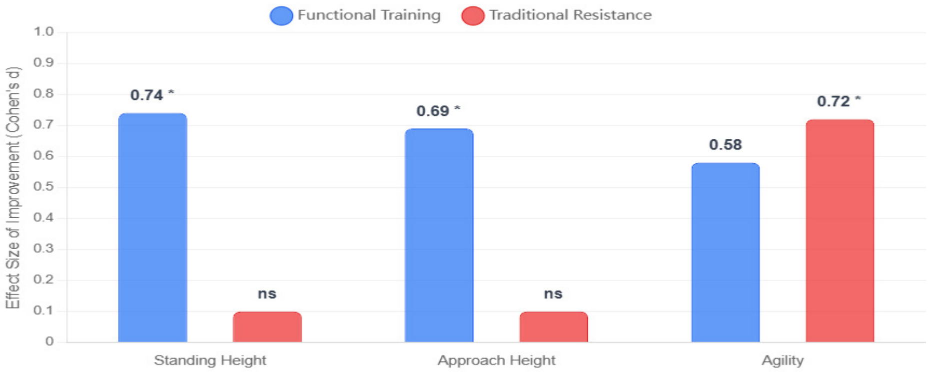

Table 1: Comparison of effect sizes for performance improvements.

DISCUSSION

The main aim of the randomized controlled trial was to re-explain the effects of training interventions under the motor learning perspective. These results confirm the initial assumption that organized functional training has a strong positive impact on motor learning in adolescent athletes. In particular, the functional training group (FTG) showed significant changes in the vertical metrics of performance such as standing reach height ($d = 0.74$) and approach reach height ($d = 0.69$). According to the motor learning point of view, they are not simply the result of muscular hypertrophy but improved neuromuscular coordination and better intermuscular synchronization. Functional training, by its nature, requires an ongoing and dynamic interaction between sensory input and motor output due to the emphasis on integrated, multi-joint and multi-planar patterns of movement. It is an active facilitator of the sensorimotor integration process, which is the underlying condition to the successful motor learning and development of complex and coordinated movement patterns (Lloyd et al., 2015; Tumkur Anil Kumar et al., 2021). Therefore, the measured increments in vertical performance are clearly indicative of optimized force transfer and coordinated activities of various muscles groups instead of isolated force generation (Silva et al., 2019; Bashir et al., 2022; Bobula et al., 2024).

Curiously, the adaptation patterns were very different in the two modalities under consideration in the context of agility performance. Although the FTG showed a modest effect size ($d = 0.58$) on agility, which could imply a beneficial effect on movement flexibility and economy, this shift did not reach statistical significance ($P = 0.075$). On the other hand, the traditional resistance training group (TRTG) had better and statistically significant changes in agility ($P = 0.028$; $d = -0.72$). Such discrepancy can be explained by the concept of specificity (Suarez et al., 2019). Due to their repetitive, linear and highly organized nature, conventional resistance exercises might be more similar to the specific biomechanical requirements of conventional agility tests. The current result highlights the fact that whereas functional training is helpful in promoting more general neural adjustment and movement economy, traditional approaches are strongly effective in particular organized physical activities (Khazaei et al., 2023). This could also account for the small gains seen in sprint and endurance measures because it has been reported before that various forms of training induce different adaptations in sprint and jump measures in young athletes (Lloyd et al., 2016; Haugen et al., 2019).

In addition to the obvious performance improvement, the significance of these results is paramount in the context of functional health. Adolescence is an especially vulnerable stage of motor development where there is fast physical maturation, hormones are fluctuating, and central nervous system flexibility is high. Nevertheless, such a fast growth may also make young athletes more susceptible to neuromuscular imbalance (Faigenbaum and Myer, 2010). Through focusing on dynamic balance, core stability, and coordination of joints, organized functional training reduces these risks and therefore it has a direct role to play in injury prevention and joint stability in the long run (Granacher et al., 2018; Liao et al., 2021). These results emphasize the necessity of incorporating the principles of functional training to youth athletic development programs to improve performance as well as long-term functional health (Wan et al., 2025).

CONCLUSION

To sum up, this paper has shown that structured functional training is a very efficient, task-based intervention that can be used to improve motor skill acquisition and functional health in adolescents who play sports. Functional training maximizes motor learning results at a vital time interval by requiring constant sensorimotor integration and encouraging the growth of multi-plane, coordinated movements. However, as evidenced by the significant increases in agility recorded in the traditional resistance training cohort, it is confirmed that traditional strength training is still a useful intervention mode when it comes to particular aspects of performance. Hence, sports scientists and coaches ought to think about implementing a synergistic strategy. Integrating both the neuromuscular and motor learning advantages of structured functional training together with particular performance adaptations of traditional resistance training could offer a more complete, time related model towards maximizing holistic athletic development and functional longevity in youth populations (Lloyd et al., 2015; Wan et al., 2025).

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