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The Effect of Reactive Neuromuscular Training on Golf Swing Kinematic Sequence

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Abstract

The purpose of this study was to examine the effect of reactive neuromuscular training (RNT) on golf swing kinematic sequence. RNT aims to develop effective dynamic stability or movement, minimize the need for verbal and visual instruction, and self-respond to stimulus created by outside force (eg. elastic band). A golf swing is a highly complex motor skill that requires multi-segments coordinative movement, such as golf kinematic sequence. To apply RNT to amateur golfers who tend to sway their body or head, inertial overloading technique utilizing clubbell (5kg) swing applied outside force (perturbation). Twenty-Four male amateur golfers were divided into two groups (RNT vs. Control). A golf ball tracking system (FlightScope Kudu) and 3D motion analysis system (K-vest) were selected for measurement devices. The experiment task was a 7-iron golf full swing. The carry distance, maximum angular velocity (pelvis, thorax, and wrist), and deceleration timing (pelvis, thorax, and wrist) were selected for dependent variables. The RNT group outperformed in carry distance. The maximum angular velocity of the pelvis and wrist were significantly higher in the RNT group. The deceleration timing of the pelvis and thorax significantly moved forward toward mid-downswing in the RNT group. The results of this study confirmed the motor learning effect of RNT on golf kinematic sequence and distance performance.

Key words: reactive neuromuscular training, motor learning, golf kinematic sequence

Introduction

A golf swing is a highly complex motor skill that requires coordination of multiple segments of the body (Knight, 2004). To maximize club head speed, golfers must make interactive movements such as proper kinematic sequence (Crews & Lutz, 2007; Neal et al., 2008; Vena et al., 2011). There have been several previous studies employing various biomechanical analyses of swings in order to improve golf performance (An et al., 2013; Hume et al., 2005; Okuda et al., 2010; Tinmark et al., 2010). However, considering the comparatively limited attentional capacity demands of the human brain, verbally demonstrating the complex information gleaned from those analyses in golf swing lessons is exceedingly difficult. In fact, application of complex and detailed information can decrease motor performance and learning effects because it can overload cognitive processing (An et al., 2013; Liao & Master, 2001; Masters et al., 2002). By contrast, application of more efficient information induces automated motion and facilitates the motor learning process (Schmidt & Lee, 2013).

Nevertheless, much of teaching in sports education

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continues to rely on the “cramming method”, wherein teachers try to explain complex and detailed movement information in learning (Janelle et al., 1997; Hebron, 2017). However, such methods can not only overload cognitive processing but also encourage excessive dependency on the instructors, degrading learners’ ability to memorize information (e.g. encoding, rehearsal, and recognition; Ross et al., 2008). Therefore, many motor learning specialists have emphasized the importance of a self-learning environment involving the use of different feedback methods (i.e. faded [progressively reducing feedback], self-controlled [giving feedback only when asked], and bandwidth [giving feedback only outside of set error tolerance limits]). Patterson & Lee (2008) emphasized the importance of self-error detection and correction in the motor learning process: “It isn’t about how much you practice. It is about how you practice.”

Accordingly, we suggest that reactive neuromuscular training (RNT) could be effectively applied in the self-learning environment. RNT is a neurological learning technique centred on “feeding the mistake”. It exaggerates performers’ mistakes in order to create an unstable environment using training aids such as elastic tubing bands (Voight & Cook, 1996). When incorrect movements are exaggerated via external perturbation, performers can better perceive proprioceptor feedback of the incorrect posture. This improved awareness of mistakes regarding movement perturbation in turn, which guides the performers towards a self-learning environment wherein they can stabilize their movements and align their joints themselves (Pittman, 2013). RNT requires minimal linguistic advice for movement correction and enhances the performer’s self-error detection and correction ability in motor learning. For example, when attempting to correct knee valgus, RNT would involve exaggerating the knee valgus by using an elastic band rather than verbal or visual feedback (Cook et al., 1999). RNT is a learning method that promotes proprioception and helps learners embody the movements required to acquire correct coordination structures. According to Fitts and Posner’s cognitive learning stages (Cognitive – Associative – Autonomous), the cognitive overload and limited problem-solving ability seen in the early stages of learning are well explained (Fitts & Posner, 1967). In this context, we can expect RNT to be effective for motor skill acquisition.

In previous studies, RNT was applied to the rehabilitation of patients with orthopaedic or neurological lesions. Female college basketball players who had anterior cruciate ligament surgery were found to have recovered knee joint stability and improved asymmetric leg strength via RNT (Cook et al., 1999). Pittman (2013) also verified the benefits of RNT through three-dimensional (3D) motion analysis. He found that knee valgus, which causes problems with the anterior cruciate ligament, showed greater improvement after RNT than after traditional resistance training. Moreover, Seada et al. (2013) investigated the benefits of RNT for walking performance among patients with Parkinson’s disease using 3D motion analysis and electromyography. They found that the RNT group – who received training in their balance with unexpected perturbation – showed dramatically improved walking performance, including walking stride, speed, fall rate, and muscle activity. Other RNT studies that have been conducted on patients with orthopaedic or neurological lesions revealed similar results. However, there have been very few studies investigating the effect of RNT on motor skill learning, such as hand grenade throw (An et al., 2016), golf skills (An & Lee, 2018; An, 2024). One of the few existing studies on simple motor skills is related to the “overarm throw” (practice hand grenade). In that study, both performance and qualitative movement analysis were conducted, and significant effects of RNT group was observed in the accuracy of performance as well as in the posture of the overarm throw (arm, torso, and leg movements).

When applying RNT to motor skill learning, it is necessary to verify a performer’s error tendencies. One of the most common swing faults among novice golfers relates to the “head or body sway” movement. More specifically, novice golfers tend to use allocentric coordination patterns, moving their heads and clubheads together in the same direction (Lee et al., 2008); therefore, kinematic sequence of deceleration timing across the three segments (pelvis, thorax, wrist) tend to appear towards the end of the downswing, rather than the mid- downswing (Putnam, 1993; Crews & Lutz, 2007). Thus, in this study, we tried to apply RNT to novice golfers who tend to commit this fault using the inertial overloading technique. Inertial overloading is based on Newton's second law (F = M × A), that is, the vector sum of the force (F) is the product of the change in mass (M) and velocity (V). We assumed that the inertia overloading technique would exaggerate the performer's head or body sway movement, thus creating more body perturbation and instability. The purpose of this study was to investigate the learning effect of RNT (i.e. the inertia overloading task) on golf performance and kinematic sequence for a full swing of a 7-iron golf club.

Methods

Participants

Twenty-four undergraduate male students participated in this study. G*Power 3.1 was used to determine the minimum sample size. 18 minimum sample size was calculated with an estimated η_p^2 value of .15, a power value of 0.90, and α value of 0.05 (An & Wulf, 2024). All participants had a one-year or less experience in golf. They were able to perform a 7-iron full swing and they all had a similar tendency of head or body sway error. The participants were divided into two groups (12 RNT group & 12 Control group). All participants had informed and agreed to the purpose and procedure of the experiment consent.

Measures

Launch Monitor

A FlightScope 3D Doppler tracking golf radar (EDH, Inc., Orlando, FL, USA) was used to measure the carry distance of a ball. This tracked the ball for its entire trajectory in 3D (elevation angles, horizontal angles, and velocity) until it landed. Its accuracy in measuring carry distance is typically within two to four yards at 250 yards, and within one to two yards at 150 yards (see: https://flightscope.com/products/legacy-products/kudu).

K-Vest Motion Analysis System

To measure the kinematic sequence of the golf swing, we used a K-vest motion analysis system (K-motion, Inc., Milford, NH, USA). The K-vest is designed specifically for golf. Three wireless inertial sensors were attached to specific body parts: pelvis (sacrum), torso (lumbar spine 3−4), and wrist (lead hand). Each individual sensor comprises a bundle of nine smaller sensors, which allows measurement of the golf swing in 3D. The maximum angular velocity and deceleration timing of the maximum angular velocity of each segment were calculated using the K-vest software algorithms. The shooting speed of each sensor was 125 Hz. Owing to the extraordinary accuracy and durability of K-vest sensors, they have been applied in many studies and training programs (Callaway et al., 2012; Henry et al., 2015) and have confirmed reliability and validity (Hong, 2005).

Procedure

The experiment proceeded in three stages (pre-test, practice phase, post-test). Prior to the pre-test, the basic golf swing instruction and mechanism were demonstrated by a professional golfer to each participant (e.g., standard grip, stance, ball position, body alignment, weight transfer, swing plane and swing arc). The experiment task was performing a 7-iron golf full swing to a 5m of golf target net (indoor golf swing room). To determine the homogeneity of golf skills among participants, 10 trials of 7-iron golf full swings were measured in the pre-test. The practice phase proceeded over the 4-week period (60 practice trials twice per week). During the practice phase, the RNT group had practiced a 7-iron golf swing with RNT technique (inertia overloading task). Control group had only practiced a 7-iron golf swing without RNT technique. The RNT groups performed the inertia loading task with a 5kg of clubbell. The inertial loading tasks were organized according to the CST clubbell swing manual (i.e. front swing, side swing, hammer swing; 3 sets of 10 repetitions). The front swing action occurred within the sagittal plane of the body, while the side and hammer swings occurred within the frontal plane. These three basic swing actions were selected in order to cause perturbations through exaggeration of the body sway in 3D space. To avoid fatigue, participants were given a three-to-five minute break between training tasks. The experiment procedures are shown in Table 1.

To examine the learning effect of RNT, we assessed a post-test after the four-weeks of practice phase. To examine the golf performance, we had participants hit 10 golf balls using a 7 iron as far as possible, while aiming at the target net. All participants wore the K-vest during the test. Velcro was used to minimize the movement of the sensors during the full swing. Before we began data collection, we had participants perform several practice swings to make them comfortable with the K-vest. After calibrating the inertia sensors (by having subjects stand upright with a static posture and hold this posture for two to three seconds), each participant performed 10 full swings with a 7 iron. The experimental setup is shown Figure 1.

Data Analyses

For data analysis, we selected three of the 10 total trials for each test period with the longest carry distance. This was because subjects were novice golfers and thus some trials were mishits, or because the ball could not be sensed by the FlightScope. For each set of five trials, we measured the carry distance, and the kinematic sequence (maximum angular velocity and deceleration timing of the pelvis, thorax, and wrist). The carry distance (m) was calculated using the FlightScope system. The carry distance was defined as the distance away from the perpendicular line from the target line

Table 1. Experimental procedure

Weeks	RNT group	Control group
0	Pre-test (10 trials of 7 iron golf full swing)	
1 2 3 4	7-Iron golf full swing [3sets of 20 trials] + RNT task [10 front swings + 10 side swings + 10 hammer swings) × 3 sets]	7-Iron golf full swing [3sets of 20 trials]
5	Post-Test (10 trials of 7 iron golf full swing)	

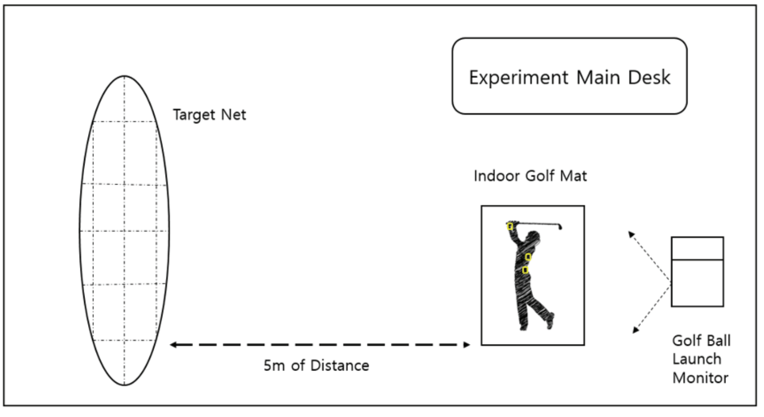

Figure 1. Experimental setup.

to the starting point (Neal et al., 2008). To calculate the kinematic sequence, we examined the maximum angular velocity (deg/sec) and deceleration timing of the maximum angular velocity (%) at the three above-mentioned segments for the normalized down-swing phase. The golf downswing phase is generally defined as the "backswing top" to the "impact position". In this study, "backswing top" (event 1) was defined as the frame where any of the three segments (pelvis, torso, wrist) starts to rotate towards the target (global x-axis). The impact position (event 2) was defined as where the wrist inertia sensor perceived a rapid impulse change from the hitting action (Tinmark et al., 2010). The dependent variables were analysed using a 2 (group: RNT, Control) × 2 (test period: Pre-test, Post-test) analysis of variance, with repeated measures for both factors. One-way ANOVA was used for post-hoc tests.

Results

Carry Distance

The results for carry distance are shown in Figure 2. As is evident, the RNT group outperformed the control group after the 4-week of practice phase. Furthermore, the main effect of the group was significant, F (1, 22) = 7.782, $p < .05$. The main effect of the test period was also significant, F (1, 22) = 45.384, $p < .001$. Additionally, the interaction of the group and test period was significant, F (1, 22) = 13.837, $p < .01$. Accordingly, one-way ANOVA was conducted to examine the simple main effect at each level. In the pre-test, there was no significant difference between groups, F (1, 22) =.558, $p > .05$. However, there was a significant difference in the post-test, F (1, 22) = 15.779, $p < .001$.

Maximum Angular Velocity

The maximum angular velocity of the pelvis tended to increase in RNT and Control groups, and the main effect of the test period was significant, F (1, 22) = 12.575, $p < .01$. The interaction of group and test period was also significant, F (1, 22) = 8.966, $p < .01$.

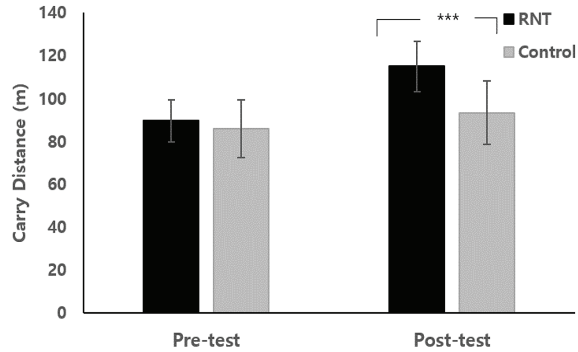

Figure 2. Carry Distance of 7-iron golf full swing.

However, the main effect of the group was not significant, F (1, 22) = 3.257, $p > .05$. One-way ANOVA was conducted to examine the simple main effect at each level. In the pre-test, there was no significant difference between groups, F (1, 22) =.136, $p > .05$. However, there was significant difference in the post-test, F (1, 22) = 7.740, $p < .05$ (Figure 3a).

The maximum angular velocity of the thorax is shown in Figure 3b. The interaction of the group and test period, F (1, 22) = 6.037, $p <$. 05, and the main effect of test period, F (1, 22) = 40.681, $p < .001$ were significant. However, the group main effect was not significant, F (1, 22) = .570, $p > .05$. One-way ANOVA was conducted to examine the simple main effect at each level. In the pre-test, there was no significant difference between groups, F (1, 22) =.117, $p > .05$. Moreover, there was no significant difference in the post-test, F (1, 22) = 2.379, $p > .05$.

Finally, the maximum angular velocity of the wrist tended to increase in both groups, but the RNT group showed a greater increase (Figure 3c). The interaction of the group and test period, F (1, 22) = 19.751, $p <$. 01, and the main effect of test period, F (1, 22) = 50.830, $p < .001$ were significant. However, the main effect of the group was not significant, F (1, 22) = 1.814, $p > .05$. One-way ANOVA was conducted to examine the simple main effect at each level. In the pre-test, there was no significant difference between groups, F (1, 22) =.309, $p > .05$. However, there was significant difference in the post-test, F (1, 22) = 8.324, $p < .01$.

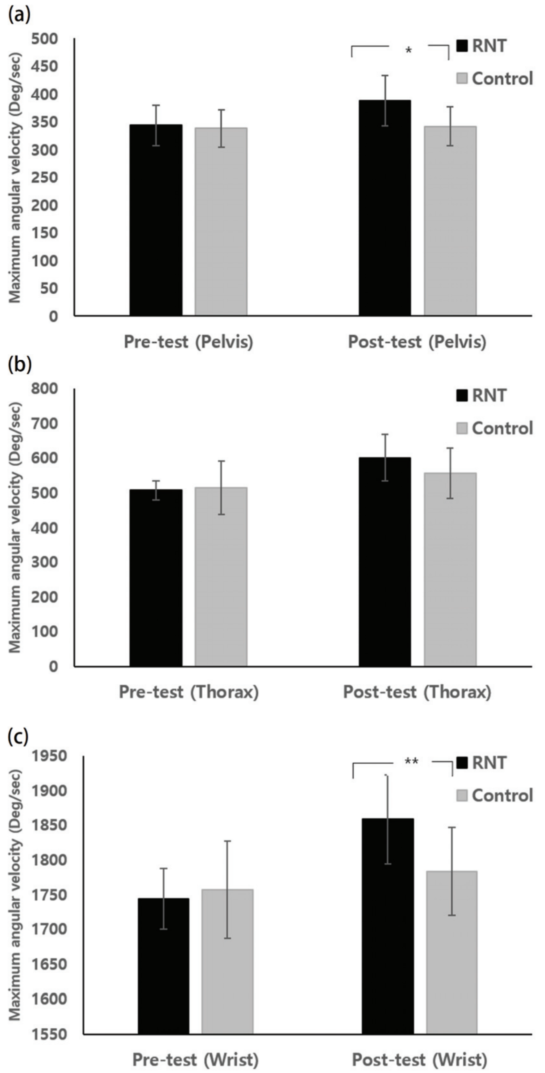

Figure 3. Maximum angular velocity (a: pelvis, b: trunk, c: wrist).

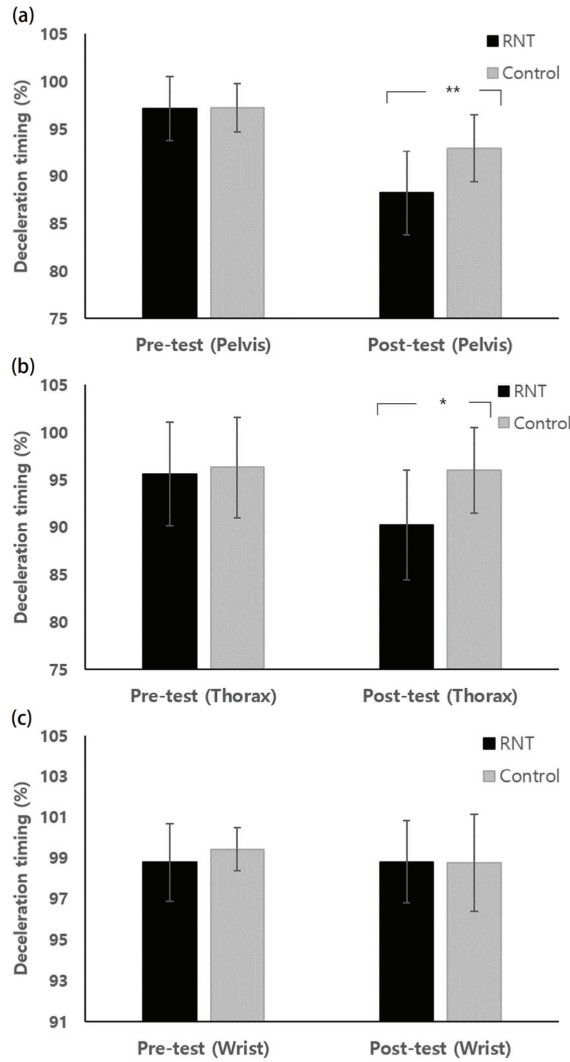

Figure 4. Deceleration timing of rotation (a: pelvis, b: trunk, c: wrist).

Deceleration Timing of Maximum Angular Velocity

The deceleration timing of the pelvis showed a dramatic forward shift in the RNT group compared with the Control group (Figure 4a). The main effect of the group was significant, F (1, 22) = 7.387, $p < .05$, and the main effect of test period was significant, F (1, 22) = 33.778, $p < .001$. However, the interaction of the group and test period was only borderline significant, F (1, 22) = 4.165, $p = .053$. One-way ANOVA was conducted to examine the simple main effect at each level. In the pre-test, there was no significant difference between groups, F (1, 22) =.005, $p > .05$. However, there was a significant difference in the post-test, F (1, 22) = 8.399, $p < .01$.

The deceleration timing of the thorax is shown in Figure 4b. The interaction of the group and test period, F (1, 22) = 4.658, $p < .05$, and the main effect of the test period were significant, F (1, 22) = 5.752, $p < .05$. However, the main effect of group was not significant, F (1, 22) = 3.203, $p > .05$. One-way ANOVA was conducted to examine the simple main effect at each level. In the pre-test, there was no significant difference between groups, F (1, 22) =.095, p > .05. However, there was a significant difference in the post-test, F (1, 22) = 7.471, p < .05.

Figure 4c shows the wrist deceleration timing. Neither the main effect of the group, F (1, 22) = .303, p > .05, nor the interaction of group and test period, F (1, 22) = .370, p > .05 was not significant. Moreover, the main effect of test period, F (1, 22) = .311, p > .05, was not significant.

Discussion

The results of the study indicated that the RNT group showed significant enhancements in the deceleration timing of the proximal segments and the kinematic sequence. As a result, the RNT group outperformed the Control group in carry distance as well as the maximum angular velocity of the pelvis and wrist. In this study, RNT involved overloading inertia to exaggerate novice golfers' head or body sway during the swing.

To understand why novice golfers move their heads with their golf swings, we must focus on the coordination strategy of different expertise. The first concept of such a coordination strategy is the "proximal-to-distal sequence" (PDS) pattern (Putnam, 1993; Hume et al., 2005; Crews & Lutz, 2007; Neal et al., 2008; Tinmark et al., 2010). Putnam (1993) emphasized that the PDS is a key element of maximizing inertia force by generating multi-joint interaction torque. The PDS pattern can be analysed in terms of the timing of maximum angular velocity. Specifically, for an expert's golf swing, the maximum angular velocity of the three segments are in a PDS pattern (pelvis-thorax-wrist), meaning that the proximal segment begins to decelerate when the distal segments accelerate. Moreover, the timing of the proximal segments' maximum angular velocity occurs in the middle of the downswing (at around 60% of the downswing phase). These results indicate that experts show a release of degrees of freedom as well as greater multi-jointed interaction torque (Dunn & Putnam, 1988). However, novice golfers' kinematic sequence is more varied. Owing to the freezing degree of freedom and reverse sequence pattern, the timing of the maximum angular velocity tends to be delayed towards the end of the downswing in a "distal-to-proximal" sequence pattern (e.g. thorax-pelvis-wrist, wrist-thorax-pelvis). Therefore, the upper body (e.g. head) sways more in the golf swing.

The most meaningful finding of this study is the deceleration sequence timing of the pelvis and trunk. Generally, wrist deceleration timing occurs near the point of impact (between 95−100%), which may explain why no significant differences were found between groups in this area. In the pre-test of this study, the proximal segments' maximum angular velocity (pelvis & trunk) appeared mostly towards the end of the downswing, at around 95−100%. However, over the 4-week practice period, the RNT group showed a dramatic timing shift forward in the downswing (pelvis: 80~90%, trunk: 85~95%). This can be interpreted as evidence of learning a more effective coordination pattern (PDS; Proximal to Distal Sequence), as required in rotational sports skills such as the golf swing. On the other hand, the Control group continued to show a similar deceleration timing sequences as the pre-test, such as simultaneous rotation timing. As a result, the RNT group outperformed the Control group in carry distance. Moreover, the maximum angular velocity of the pelvis and wrist showed significant improvements in the RNT group. These results imply that the RNT group learned more effective coordination in order to maximize club head speed by maintaining a centre arc in their golf swing. In previous studies, the temporal relations of the proximal-to-distal sequence were also emphasized as a critical factor related to accuracy performance (Furuya & Kinoshita, 2007; Hirashima et al., 2007). This is because early deceleration of the proximal segments would generate better multi-joint interaction (Tinmark et al., 2010).

The second concept of the coordination strategy is an allocentric and egocentric coordination pattern. Lee et al. (2008) examined the coordination of the head and putter movement in expert and novice golfers and demonstrated that the motionless head movement observed in expert golfers was because they followed an egocentric coordination pattern: that is, their head and putter movements were tightly coupled but in opposite directions. Conversely, novice golfers used an allocentric coordination pattern: that is, they moved their head and putter together in the same direction. Later, Lee et al. (2008) demonstrated that experts' egocentric coordination pattern was the optimal strategy for stabilizing body movement with enhanced power during a golf swing. These results explain why the deceleration timing of proximal segments appears towards the middle of the downswing in expert golfers and towards the end of the downswing in less skilled golfers with simultaneous rotation strategy.

Based on this evidence, it is possible that novice golfers can learn an egocentric coordination pattern (i.e. a counter-balancing strategy or an early deceleration of the proximal segments) after 4 weeks of RNT. Newell (1991) demonstrated the "search strategy" concept in motor skill acquisition. Specifically, the search strategy refers to an individual's process of learning optimal motor solutions for their perceptual-motor workspace (Newell et al., 1989) – that is, learning how to coordinate one's perceptual environment with the action environment in a way that is consistent with the task constraints (Newell, 1991). RNT provides a self-learning environment, and thus forces performers to search for optimized coordination for their unstable environment through proprioceptive feedback. Shadmehr and Mussa-Ivaldi's (1994) robot arm stretch experiment indirectly explains how optimal coordination can be acquired in a self-learning environment via a search strategy. In their task, which involved reaching a targeted point with a hand, a robotic device was used to disturb the reaching action. In the early stage of training, performance errors increased notably, but the stability of hand motion gradually improved with repetition. This result implies that the subjects learned a compensation strategy and optimal movement in an unstable environment through a "search strategy". Moreover, Kelso (1984) demonstrated a phase transition into more stable and functional attractors by increasing the speed of a bi-manual finger coordination task. The RNT group might have experienced a phase transition to obtain a more stable attractor.

Indoctrination teaching methods, such as repetitive verbal feedback or informing learners of detailed movements for each performance, might delay learning by overloading learners' information processing and cultivate dependence on instructors. To speed-up learning, performers should detect and solve problems that they encounter with their performance by themselves. Creative instructors should be able to design effective RNT solutions that induce a self-learning environment. As RNT remains a new approach in motor skill learning studies, we expect future research to conceive applications for RNT in various motor learning situations. In addition to the inertial overload approach using weight, RNT can also be applied through the principle of elastic resistance using tools such as TheraBands (An, 2024).

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Author Contributions

Conceptualization: An JongSeong
Data curation: An JongSeong
Formal analysis: An JongSeong
Investigation: An JongSeong
Project administration: An JongSeong
Writing-original draft preparation: An JongSeong
Writing-review and editing: An JongSeong

Conflict of Interest

The author declare no conflict of interest.

References

An, J. S. (2024). The Influence of reactive neuromuscular training utilizing the principle of elastic force on learning golf putting. *Journal of Golf Studies*, **18(3),** 85–95.

An, J. S., & Wulf, G. (2024). Golf skill learning: An external focus of attention enhances performance and motivation. *Psychology of Sport and Exercise*, **70,** 102563.

An, J. S., Kim, S. J., Suh, S. H., Lee, S. W., Sung, H. Y., & Lee, S. M. (2016). The influence of 6 weeks reactive neuromuscular training (RNT) on hand grenade throw performance and qualitative motion analysis. *The Korean Journal of Physical Education,* **55(6)**, 145–156.

An, J. S., Lee, S. M. (2018). The Influence of Reactive Neuromuscular Training (RNT) on Beginner Golfer's Pitch Shot Accuracy and Head-clubhead Coordination. *Korean Society of Sport Psychology,* **29(1),** 79–89.

An, J. S., Wulf, G., & Kim, S. J. (2013). Increased carry distance and X-factor stretch in golf through an external focus of attention. Journal of Motor Learning and Development, **1,** 2–11. doi:10.1123/jmld.1.1.2

Callaway, S., Glaws, K., Mitchell, M., Scerbo, H., Voight, M., & Sells, P. (2012). An analysis of peak pelvis rotation speed, gluteus maximus and medius strength in high versus low handicap golfers during the golf swing. *The International Journal of Sports Physical Therapy*, **7,** 288–295. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3362989/

Cook, G., Burton, L., & Fields, K. (1999). Reactive neuromuscular training for the anterior cruciate ligament-deficient knee: a case report. *Journal of Athletic Training*, **34,** 194–201. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1322908/

Crews, D., & Lutz, R. (2007). Comparison of kinematic sequence parameters between amateur and professional golfers. *Science and Golf*, **5,** 30–36.

Dunn, E. G., & Putnam, C. A. (1988). The influence of lower leg motion on thigh deceleration in kicking. In G. de Groot, A. P. Hollander, P. A. Huijing, G. J. van Ingen Schenau (Eds.), *Biomechanics XI-B* (pp.787–790). Englewood Cliffs, NJ: Free University Press.

Fitts, P. M., & Posner, M. I. (1967). *Human performance. Brooks & Cole*, Belmont: California.

Furuya, S., & Kinoshita, H. (2007). Roles of proximal-to-distal sequential organization of the upper limb segments in striking the keys by expert pianists. *Neuroscience Letters*, **421,** 264–269. doi:10.1016/j.neulet.2007.05.051

Hebron, M. (2017). *Learning with the brain in mind: Mind sets before skill sets*. Smithtown, NY: Learning Golf Inc.

Henry, E., Berglund, K., Millar, L., & Locke, F. (2015). Immediate effects of a dynamic rotation specific warm-up on X-factor and X-factor stretch in the amateur golfer. *The International Journal of Sports Physical Therapy*, **10(7),** 998–1006.

Hirashima, M., Kudo, K., Watarai, K., and Ohtsuki, T. (2007). Control of 3D limb dynamics in unconstrained overarm throws of different speeds performed by skilled baseball players. *Journal of Neurophysiology*, **97,** 680–691. doi:10.1152/jn.00348.2006

Hong, H. (2005). *Correlation between pelvic rotation and gluteus maximus strength in golfers*. Unpublished master's dissertation. California University of Pennsylvania, Pennsylvania.

Hume, P., Keogh, J., & Reid, D. (2005). The role of biomechanics in maximising distance and accuracy of golf shots. *Sports Medicine*, **35,** 429–449. doi: 10.2165/00007256-200535050-00005

Janelle, C. M., Barba, D. A., Frehlich, S. G., Tennant,

L. K., & Cauraugh, J. H. (1997). Maximizing performance feedback effectiveness through videotape replay and a self-controlled learning environment. *Research Quarterly for Exercise and Sport*, **68,** 269–279. doi:10.1080/02701367.1997.10608008

Kelso, J. A. S. (1984). Phase transitions and critical behavior in human bimanual coordination. *American Journal of Psychology: Regulatory, Integrative, and Comparative Psychology*, **15,** 1000–1004.

Knight, C. A. (2004). Neuromotor issues in the learning and control of golf skill. *Research Quarterly for Exercise and Sport*, **75,** 9–15. doi:10.1080/02701367.2004.10609128

Lee, T. D., Ishikura, T., Kegel, S., Gonzalez, D., & Passmore, S. (2008). Head-putter coordination patterns in expert and less skilled golfers. *Journal of Motor Behavior*, **40(4),** 267–272.

Liao, C. M., & Masters, R. S. (2001). Analogy learning: A means to implicit motor learning. *Journal of Sports Sciences*, **19,** 307–309.

Masters, R. S., Law, J., & Maxwell, J. (2002). Implicit and explicit learning in interceptive actions. In K. Davids, G. Savelsbergh, S. J. Bennett, & J. van der Kamp (Eds.), *Interceptive actions in sport: Information and movement* (pp. 126–143). London: Routledge.

Neal, R., Lumsden, R., Holland, M., & Mason, B. (2008). Body segment sequencing and timing in golf. *International Journal of Sports Science & Coaching*, **2,** 25–36. doi:10.1260/174795407789705497

Newell, K. M. (1991). Motor skill acquisition. *Annual Review of Psychology*, **42,** 213–237. doi:10.1146/annurev.psych.42.1.213

Newell, K. M., Kugler, P. N., van Emmerik, R. E. A., & McDonald, P. V. (1989). Search strategies and the acquisition of coordination. In S. A. Wallace (Ed.), *Perspectives on the coordination of movement* (pp. 85–122). Amsterdam: Elsevier.

Okuda, I., Gribble, P., & Armstrong, C. (2010). Trunk rotation and weight transfer patterns between skilled and low skilled golfers. *Journal of Sports Science and Medicine*, **9,** 127–133.

Patterson, J. T., & Lee, T. D. (2008). Organizing practice: The interaction of repetition and cognitive effort for skilled performance. In D. Farrow, J. Baker, & C. MacMahon (Eds.), *Developing sport expertise: Researchers and coaches put theory into practice* (pp. 119–134). London: Routledge.

Pittman, M. (2013). *Biomechanical Differences at the knee after two types of hip abductor training: Traditional vs. Reactive neuromuscular training*. Unpublished master's thesis. California State University, Fullerton.

Putnam, C. A. (1993). Sequential motions of body segments in striking and throwing skills: Descriptions and explanations. *Journal of Biomechanics*, **26,** 125–135.

Ross, M., Blatz, C. W., & Schryer, E. (2008). Social memory processes. In J. H. Byrne (ed.), *Learning and Memory: A Comprehensive Reference* (vol. 2, pp. 911–926). Oxford: Elsevier

Schmidt, R., & Lee, T. (2013). *Motor Learning and performance, 5E with web study guide: From principles to application*. Champaign, IL: Human Kinetics.

Seada, Y., Elsayed, E., & Talat, W. (2013). Impact of reactive neuromuscular training on falling in Parkinson's disease. *Indian Journal of Physiotherapy & Occupational Therapy*, **7,** 65–70. doi:10.5958/j.0973-5674.7.2.015

Shadmehr, R., & Mussa-Ivaldi, F. A. (1994). Adaptive representation of dynamics during learning of a motor task. *The Journal of Neuroscience*, **14,** 3208–3224. Retrieved from https://pdfs.semanticscho lar.org/1ceb/2b896dc43caa569a0f1aa2906ea661502d13.pdf

Tinmark, F., Hellstrom, J., Halcorsen, K., & Thorstensson, A. (2010). Elite golfers' kinematic sequence in full- swing and partial-swing shots. *Sports Biomechanics*, **9,** 236–244. doi: 10.1080/14763141.2010.535842

Vena, A., Budney, D., Forest, T., & Carey, J. P. (2011). Three-dimensional kinematic analysis of the golf swing using instantaneous screw axis theory, Part 2: Golf swing kinematic sequence. *International Sports Engineering Association*, **13,** 125–133. doi: 10.1007/s12283-010-0059-7

Voight, M. L., & Cook, G. (1996). Clinical application of closed kinetic chain exercise. *Journal of Sport Rehabilitation*, **5,** 25–44. doi: 10.1123/jsr.5.1.25