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Age, Gender, and Flexibility Differences in Tennis Serving Among Experienced Older Adults

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This study examined tennis serving in older adult tennis players. Twenty-two older adults, divided into younger and older halves, were videotaped serving five "first" serves. Dominant shoulder flexibility also was measured. From the videotape, servers were classified into developmental levels and their resultant ball impact velocity was calculated. An Age × Gender (2 × 2) mixed model MANOVA yielded no significant differences between the age groups or between men and women in flexibility, ball impact velocity, or movement pattern. A few combinations of the developmental levels of elbow and forearm/racket action were used by the majority of servers. Regular practice might consolidate older adults in these attractor movement patterns, making them more resilient to change than with less practiced skills. These results suggest practice in older adulthood favorably affects performance by resulting in consistency of movement pattern and maintenance of movement pattern, flexibility, and ball impact speed.

Key Words: motor skill, aging, movement, dynamic systems

Many perspectives on development successfully address developmental change for one part of the life span but lack an explanation for change in other age periods. For example, the maturation perspective was used by developmentalists for decades to explain motor development in infancy and early childhood (Clark & Whitall, 1989a). That is, maturation of the central nervous system was invoked as the sole force that drove change in behavior. Other systems, their interaction, and the environmental context in which behavior occurred were all discounted. Maturationists, though, mostly studied infants and young children (Gesell, 1946; McGraw, 1946). They did not attempt to apply their perspective to life span development.

Learning (experiential or behavioral) perspectives emphasized the environment, especially the inherent and augmented feedback in the environment, as the

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force driving behavioral change. Carried to the extreme, these perspectives included the idea that behavior could be completely controlled by feedback. Behaviorists ignored change within the individual, that is, the change of systems with the growth and maturation of the young or the aging of older individuals.

A more recent perspective, the dynamic systems perspective, not only offers rich explanations for developmental change in specific parts of the life span but has the potential to be applied to the entire life span. The dynamic systems perspective differs from other theoretical frameworks in that it considers the cooperative role played by many interacting systems simultaneously. According to this perspective, change within each separate system and interaction among systems are what drives developmental change (Thelen, Ulrich, & Jensen, 1989). For example, maturationists sought to explain new behaviors by maturation of the nervous system. In contrast, dynamicists view the occurrence of change as the result of the interaction of many systems, like skeletal, muscular, nervous, postural, and environmental systems. With the dynamic systems perspective, it is important to determine the current status of individual systems, as well as their interactive effects. For example, investigators might wish to discover the impact of changes in strength on the postural system of an individual with osteoporosis.

Dynamicists hold that movement is shaped by the various systems acting together (Kelso & Schoner, 1988), so new or different behaviors result from change in one or more systems. A change in one system might reach some critical point and bring about a reorganization in movement behavior. For example, an older adult who enjoys jogging may gradually lose range of motion in the knee joint. Initially, extended stretching may restore most mobility so that running is only minimally affected. Once past some critical point, however, our jogger may be unable to regain mobility through stretching and unable to exert enough force to project the body off the ground. Walking may now replace jogging as the preferred mode of exercise.

In this example, range of motion at the knee acts as a rate controller for jogging. Thelen and Ulrich (1991) defined a rate limiter, or rate controller, as the slowest changing component in a developing system during youth. Here the concept is extended to define a rate controller as the slowest changing component in a youthful developing system or the fastest changing component in an aging system (Haywood, 1993). The component must reach a critical, threshold level before a shift to a new behavior occurs. Over the life span, different systems may control how behaviors are manifested at different points. The dynamic systems perspective thus can account for change in youth by advancement of systems and change in older adulthood by (the often) decline of systems.

It is important, both theoretically and practically from the dynamic systems perspective, to identify the rate-controlling systems of older adulthood. Change in a system beyond a certain critical value may result in reorganization of a movement pattern. Decline in one system might force change in another system as the performer attempts to compensate for the change. As a result of declines in strength or range of motion (musculoskeletal system), movement speed (central or peripheral nervous systems), or other systems, an older individual might have to move in a way different than what was possible earlier. "New" movements are most often less advanced, particularly when force production is required. For example, length of backswing is associated with limb/

implement speed at release/impact in ballistic skills. Shortening the backswing likely reduces speed. These new movement patterns might be modifications of previously used patterns that compensate for some kind of loss, or they might represent an actual loss of skill. For example, an older thrower with limited shoulder flexibility might modify a downward, circular backswing by curtailing the backswing or might change to simple outward rotation of the upper arm in an abducted position.

Some of the rate-controlling systems are identified for childhood skills (Clark & Whitall, 1989b). For example, muscular strength and postural control are likely rate controllers for upright walking (Clark & Phillips, 1993). But little is known about rate-controlling systems or factors for older adults. Changes in both movement speed and movement pattern have been widely described for older adults. It is likely that these changes are driven by changes in one or more systems. Some researchers note that movement slows among older adults without a concomitant change in movement pattern itself (Craik, 1989; Klinger, Masataka, Adrian, & Smith, 1980, cited in Adrian, 1980; Schwanda, 1978). Others note both movement slowing and change in movement pattern (Nelson, 1981; Williams, Haywood, & VanSant, 1990, 1991, 1993).

This body of research demonstrates that the relationship between movement speed and movement pattern is uncertain for older adults and suggests that rate controllers may influence change in movement speed or movement pattern. Range of motion (changes in the musculoskeletal system) may be a rate controller in older adults. Haywood, Williams, and VanSant (1991) explored the impact of range of motion on the overarm throwing pattern in older adults. They found that individuals categorized at high developmental levels in the backswing action of the overarm throw for force (those levels characterized by circular backswings) tended to have 90° of lateral rotation of the humerus. Some individuals categorized at lower developmental levels had less available rotation, which suggests a relationship between range of motion and movement pattern.

The purpose of this study was to examine the movement pattern used and the ball velocity at impact generated by older adult tennis players as they executed an overarm tennis serve. Musculoskeletal shoulder flexibility was analyzed as a possible rate controller for the movement pattern.

Little research has been conducted examining the tennis serve movement pattern in older adults, but the tennis serving motion is similar to the overarm throwing motion. The overarm throwing patterns and velocities used by older adults have been studied (Williams et al., 1990, 1991, 1993; Haywood et al., 1991). Existing studies of throwing patterns usually involved adults not engaged in throwing activities on a regular basis. The adults in the present study, however, were regular tennis participants so the influence of factors such as task novelty and participant fear of injury with a maximal effort could be minimized. Also, experience with the skill and the amount of practice and instruction could be documented. It was hypothesized that advanced movement patterns would be associated with faster ball impact speed, and greater range of motion at the shoulder would be associated with higher level movement patterns. Following the findings on throwing, it also was hypothesized that older women would have slower ball impact velocities than older men and that the more elderly of the group would have less flexibility, slower impact velocities, and lower level movement patterns.

Method

SUBJECTS

Eleven men and 11 women participated in this study. All were current participants in regular tennis programs or games. The average age of the group was 68.7 years (SD = 4.9). The youngest was 62 and the oldest 81. The average age of the women was 67.7 (SD = 3.7) and of the men 69.7 (SD = 5.9). For some of the data analyses the group was split into a younger and an older half. The dividing age was 68 years. Five men and 6 women were in the younger group and 6 men and 5 women in the older group.

Subjects reported they played tennis an average of 2.7 times per week. The lowest frequency reported was once per week by 3 players, but 5 players said they played four, five, or six times per week. Most of these seniors said they had played tennis for decades. The group averaged 39.8 years (SD = 17.8) of tennis play. The least experience was 6 years.

MEASUREMENTS

All of the subjects were videotaped serving on a tennis court, had their dominant shoulder flexibility measured, and answered a questionnaire. The seniors were videotaped sagittally by a camcorder at a shutter speed of at least 1/500 s. The camcorder's view was along a line approximately 30 cm behind and parallel to the tennis court baseline and perpendicular to the line of action. The camcorder was positioned to the server's dominant side approximately 7 m away. Right-handers served to the left service court, and left-handers served to the right service court. Five serves that landed in or near the service court were recorded. A measure of known length was always visible in the scene. Two types of measurements were taken from the videotapes.

Impact Ball Velocity. Ball velocity at impact was determined for five serving trials. We determined x- and y-coordinates for several video frames before and after ball impact, using a Peak Performance Video Analysis System. Resultant ball velocity was computed from these coordinates and analyzed in a $2 \times 2 \times 5$ (Age × Gender × Trial) ANOVA with repeated measures on the last factor. As there was no significant trials effect nor any significant interaction effects ($p >$ .05), ball impact velocity was collapsed across trials.

Movement Pattern. Qualitative assessments of the movement patterns used in serving were conducted. The three components of the tennis serve analyzed were preparatory trunk action, elbow action during the force production phase, and forearm/racket actions during force production. These components were found to meet criteria (comprehensiveness, stability, and adjacency; interobserver reliability of 80% or better; intraobserver reliability of 80% or better) as developmental sequences, as established in a prelongitudinal study by Messick (1991) on tennis players 9 to 19 years of age. Although these sequences should ultimately be confirmed by longitudinal study, Messick's investigation at least suggested that these three components undergo age-related change. The following list provides descriptions of the developmental levels for each of the three components.

Preparatory trunk action

- Step 1: No trunk action or flexion/extension of the trunk
- Step 2: Minimal trunk rotation (<180°)
- Step 3: Total trunk rotation (>180°)

Elbow action

- Step 1: Elbow collapsed
- Step 2: Elbow partially flexes (≥90°) and extends forward or upward
- Step 3: Elbow flexes (≤90°) and extends upward

Forearm/racket action

- Step 1: No forearm/racket lag
- Step 2: Forearm/racket lag
- Step 3: Delayed forearm/racket lag and upward extension[1]

Flexibility. Single static shoulder flexibility measures were taken from a backlying position (Kendall, McCreary, & Provance, 1993, pp. 63-64). The experimenter had been trained by a physical therapist to take the flexibility measures. Shoulder flexion was measured from a starting position with the arm at the side to a position as far overhead as possible. Lateral rotation of the humerus was measured from a starting position wherein the shoulder was abducted 90° and the elbow flexed 90°, with the forearm therefore perpendicular to the floor. Humeral rotation was indicated by translation of the forearm through an arc measured from this starting position.

Questionnaire. The questionnaire asked participants (a) about a range of conditions (e.g., arthritis or diabetes) and injuries that could affect flexibility, (b) about their tennis experience, and (c) about the instruction they had received in tennis, particularly the serve. An open-ended question asked if participants had changed their serve as they had aged. Although this questionnaire provided only self-report data, the intention here was to use the information broadly, for description or categorization.

PROCEDURE

After participants read and signed informed consent materials, they were given an opportunity to warm up. When ready, they were instructed to perform five "first" serves, as they normally would in playing tennis. Servers were not told that their serve had to land in the service court; in fact, only serves that did not land in or near the court or hit the top of the net were repeated. This procedure was used to encourage servers to produce their most forceful serve and not trade off speed for accuracy because they were being videotaped.

After participants served, their shoulder flexibility was measured and they completed the questionnaire. The entire procedure took 20 min or less.

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[1]From *Research Quarterly for Exercise and Sport*, Vol. 62, September 1991, "Prelongitudinal Screening of Hypothesized Developmental Sequences for the Overhead Tennis Serve in Experienced Tennis Players 9–19 Years of Age" (p. 250) by J.A. Messick. *The Research Quarterly for Exercise and Sport* is a publication of the American Alliance for Health, Physical Education, Recreation and Dance, 1900 Association Dr., Reston, VA 22091.

Design. A 2 × 2 (Age × Gender) multivariate mixed model analysis of variance (Schutz & Gessaroli, 1987) was calculated to analyze all the dependent variables, specifically, lateral rotation of the humerus, shoulder flexion, preparatory trunk developmental level, elbow action developmental level, forearm/racket action developmental level, and ball impact velocity. This analysis was chosen to accommodate the sample size. A total of 110 trials were analyzed.

Results

RELIABILITY

Both intrarater reliability and interrater reliability were calculated for the qualitative assessment of the movement patterns used in the tennis serve. The first author categorized all trials of the tennis serve for all subjects, as did a second, trained rater. Agreement between raters was 95% for preparatory trunk action, 75% for elbow action, and 80% for forearm/racket action. The first author repeated the assessment on a subset of the sample (n = 10) several weeks later. Intrarater agreement was 100% for trunk and elbow action and 80% for forearm/racket action.

FLEXIBILITY

Flexibility differences between men and women and younger and older participants were analyzed in the mixed model MANOVA. There were no significant differences in range of motion between the groups for either lateral rotation or flexion of the humerus; however, the difference between women and men in lateral rotation approached significance. Women averaged 85.5° of lateral rotation (SD = 7.0), but the men averaged only 73.9° (SD = 16.5), $F(1, 17) = 4.15$, p = .0575. With respect to humeral flexion, women also demonstrated more range of motion, 168.9° (SD = 12.7) versus 160.5° (SD = 10.9), but the difference was not significant, $F(1, 17) = 2.39$, $p = .14$.

IMPACT BALL VELOCITY

Resultant ball velocity at impact also was analyzed in the mixed model MANOVA. No significant differences were detected for gender, $F(1, 17) = 0.12$, $p = .73$. As expected, male subjects' service impact velocity was higher than that of the females (24.6 vs. 23.7 m/s), although the difference was small and not significant. Interestingly, individual male performers had the fastest and the slowest serving velocities, 34.3 and 16.6 m/s, respectively. The range of velocities determined for women was nearly as great, however (32.5 and 18.2 m/s).

There was no significant difference between the younger and older participants, $F(1, 17) = 0.64$, $p = .44$. In fact, the mean velocity of the younger group was only slightly faster than that of the older group, 24.9 and 23.3 m/s, respectively.

MOVEMENT PATTERN

All five serves for each subject were categorized into a developmental level. The modal level was used in all analyses; however, only one trial (0.9% of the 110 trials) was categorized as other than what proved to be the modal level. That is, servers' movement patterns were remarkably consistent.

Most of the developmental levels were observed in the older adult servers. For preparatory trunk action, 1 server was at Level 1, 3 were at Level 3, and the remainder were at Level 2. Figure 1 shows the developmental levels for preparatory trunk action for men and women separately and combined. For elbow action, 5 servers were at Level 1, 8 at Level 2, and 9 at Level 3 (see Figure 2). For forearm/racket action, 3 servers were at Level 1, 14 at Level 2, and 5 at Level 3 (see Figure 3). Two servers, 1 man and 1 woman, demonstrated the Level 3 pattern in all three components. Overall, the developmental level of the senior servers was moderate except that elbow action was somewhat more advanced.

The mixed model MANOVA tested for differences in the three components of the movement pattern. There were no significant main or interaction effects between the men and women, forearm $F(1, 17) = 0.35$, $p = .56$; elbow $F(1, 17) = 1.24$, $p = .28$; trunk $F(1, 17) = 0.0$, $p = 1.0$. Nor were there significant effects between the younger and older participants, forearm $F(1, 17) = 3.67$, $p = .07$; elbow $F(1, 17) = 3.69$, $p = .07$; trunk $F(1, 17) = 0.0$, $p = 1.0$. Correlation

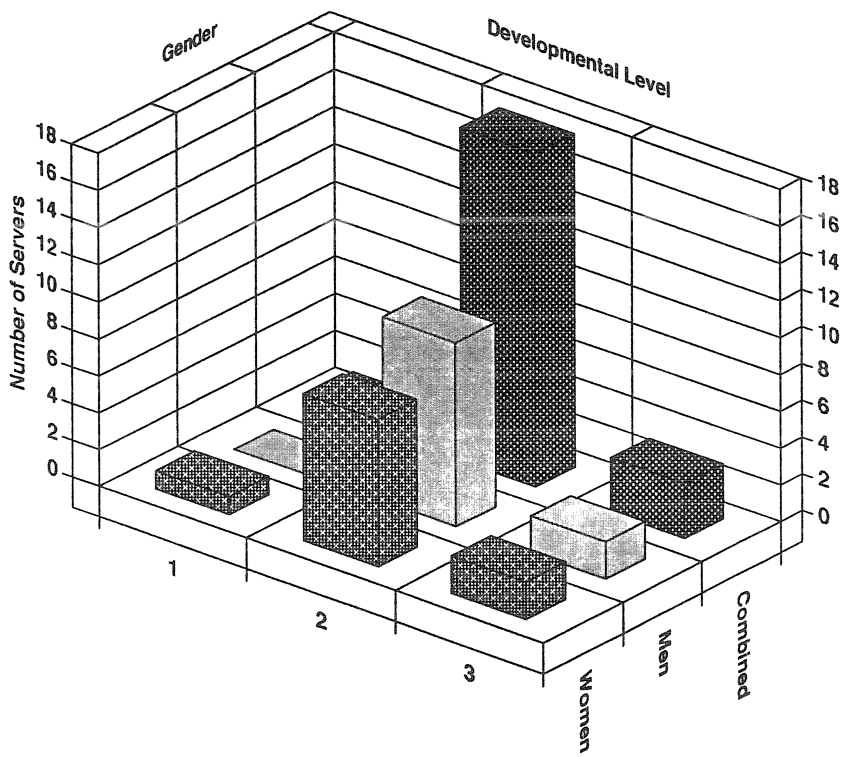

Figure 1. Developmental levels of preparatory trunk action in tennis serving for men and women separately and the entire group combined.

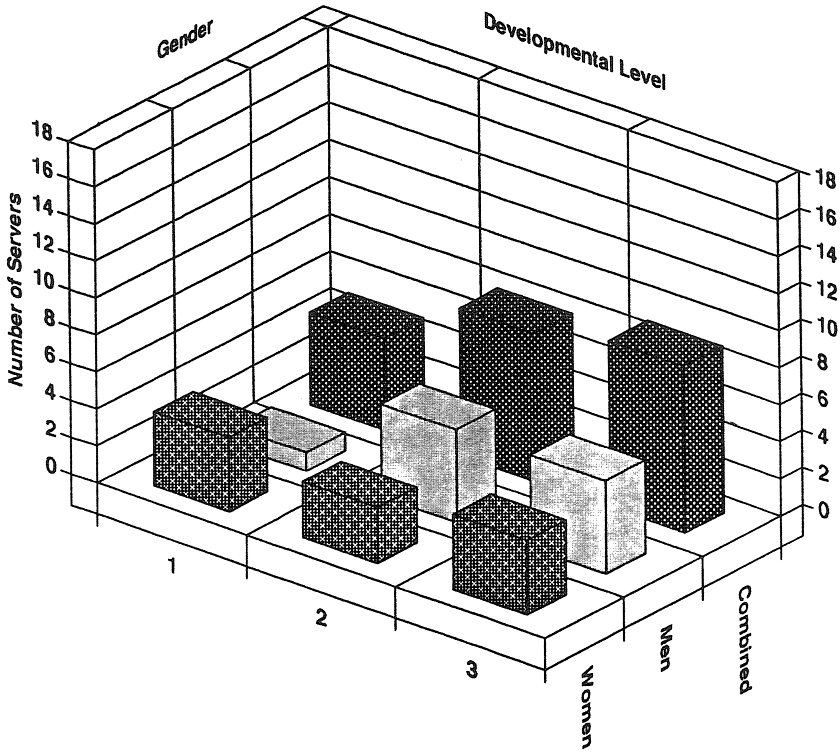

Figure 2. Developmental levels of elbow action during force production in tennis serving for men and women separately and the entire group combined.

coefficients were calculated between velocity and developmental level in each body component. The coefficients were low but positive, ranging from .25 to .29.

As would be expected, the 9 servers with mechanically more advanced elbow action (i.e., those who reached up to contact the ball) had a higher mean ball impact velocity, 25.9 m/s, than the other 13 servers, 23.1 m/s. The 5 servers with advanced forearm/racket action also had a higher velocity, 27.2 m/s, than the other 17 servers, 23.4 m/s. Only 4 servers had both Level 3 elbow action and Level 3 forearm/racket action. Three of these 4 servers had mean ball impact velocities that were among the fastest in the sample, approximately 1 or more standard deviations above the group mean. Three servers had equally fast impact velocities but movement patterns that were less developmentally advanced.

Correlation coefficients were calculated between flexibility measures and developmental levels. Of particular interest were relationships between flexibility and elbow and forearm/racket action, since the most advanced movement pattern involved (a) allowing the arm and racket to lag with the upper arm laterally rotated and (b) reaching up overhead to contact the ball. However, the correlation coefficients were positive but low (r = .01 to .33). Forearm/racket lag (Levels 2 and 3) was not necessarily associated with greater range of motion for lateral

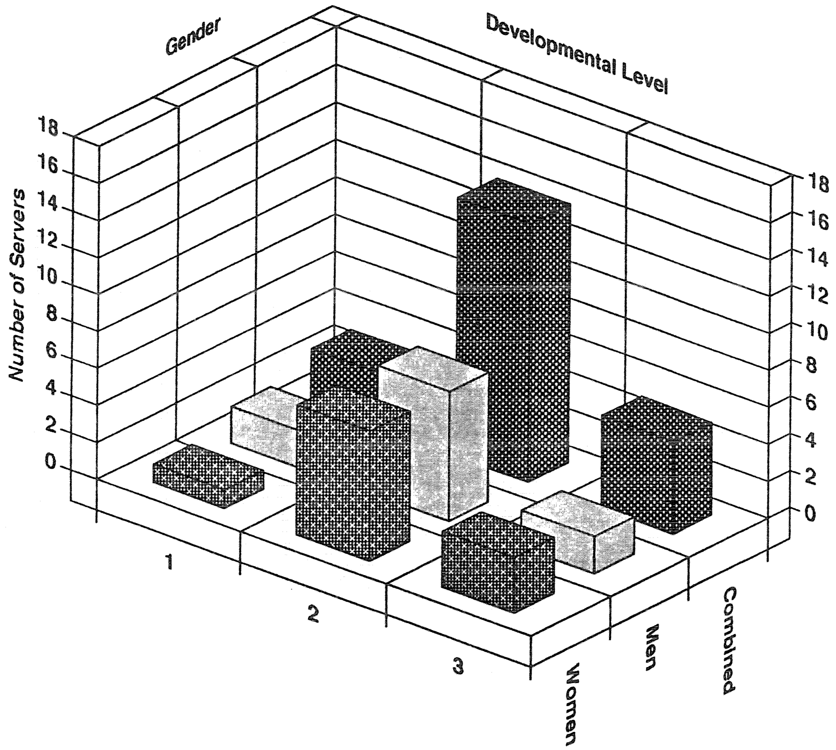

Figure 3. Developmental levels of forearm/racket action during force production in tennis serving for men and women separately and the entire group combined.

rotation. On the other hand, servers at Level 3 of elbow action, which necessitated reaching up to contact the ball, averaged 188° of shoulder flexibility whereas those at Levels 1 and 2 averaged 151°. The smallest range of motion of any server with Level 3 elbow action was 153°. Of the 2 servers who demonstrated the most advanced movement pattern, 1 had some limitation in static shoulder flexibility but both had nearly full range of motion for lateral rotation of the humerus.

Discussion

It seems reasonable that limited range of motion in the shoulder joint would at some point preclude use of certain movement patterns. However, evidence that static flexibility of the shoulder joint is a rate controller for tennis serving in older adults is very limited. There was a trend for more flexible servers to use more advanced movement patterns, but individual servers provided notable exceptions. Possibly, among those who are able to execute the overarm tennis serve at all, relatively small losses of flexibility do not ''scale down'' range of motion enough to drive reorganization of the movement pattern. That is, the critical level of static flexibility that would drive reorganization of the movement pattern was not reached by the present subjects. Declines in shoulder flexibility over the older adult years in other populations have been documented (Murray, Gore, Gardner, & Mollinger, 1985). Regular practice of tennis strokes might help to maintain sufficient range of motion at the shoulder joint since there were no differences here between the younger and older players in range of motion.

It is possible that static measures of flexibility are not very indicative of functional movements. Static flexibility measures are initiated in a neutral joint position, and only one joint is measured at a time. Functional movements such as the tennis serve are multisegmented movements. Rather than arising from a significant loss of range of motion in a single joint, perhaps the limitation to a functional movement arises from smaller losses at adjacent joints and the shortening of multijoint muscles. The notion that an accumulated loss of flexibility at adjacent joints acts as a rate-controlling factor deserves future research attention.

In contrast to previous studies of older adults executing an overarm throw, this study found no significant differences between men and women tennis servers. The throwers and servers were alike in that both groups were active in their older years. They differed in that the throwers rarely practiced throwing while the servers regularly engaged in tennis play that included serving. Women throwers reported limited experience with throwing activities, especially since their school days. It is possible that the women servers, because they regularly participated in tennis, benefited from one or more of a variety of factors that resulted in a mean movement pattern and ball impact velocity that were similar to patterns and velocities of the men servers. Earlier studies (Butterfield & Loovis, 1993; Halverson, Roberton, & Langendorfer, 1982) found that differing amounts of practice were a factor in gender differences between young throwers. At any age, increased practice of the service movement can help improve strength, smooth weight transfer, provide opportunities for formal or informal instruction, and provide opportunities for imitation of observed models. When the amount of practice and the extent of experience are more equal, as they were between these older adult men and women, the effect is to minimize gender differences.

The hypothesis of age differences within this group of older adult servers was not supported, although trends in the direction of decline with advancing age were noted. The sample size here might have been too small to reveal significant differences, but also it is possible that the stereotype of rapidly declining skill in the 60s and 70s does not apply to well-learned and regularly practiced skills. There were two servers who used a Level 3 movement pattern for each of the three components observed. Obviously, these two servers had reached the most advanced level in each component and maintained this movement pattern. Both servers, 1 man and 1 woman, had been tennis teaching professionals.

Of the nine possible combinations of elbow and forearm/racket action, each having three levels, seven combinations were observed in these 22 servers, but 15 servers fell into three combinations. These three combinations were Level 2 of both elbow and forearm/racket action, Level 2 of elbow but Level 3 of forearm/racket action, and Level 3 of both elbow and forearm/racket action. The numbers of servers in each combination were 6, 5, and 4, respectively.

Roberton and Langendorfer (1993) proposed that, from the dynamical perspective, the range of movement patterns for a task is like a landscape with hills and valleys. The valleys represent the most commonly observed movement patterns because performers are attracted to them just like rainwater falling on hills is "attracted" to the valleys. These common patterns are termed *attractor* patterns. The hills represent movement patterns less commonly observed in performers. At points the valleys branch. Similarly, at points in development performers may be pushed to a different attractor movement. The push to another attractor movement pattern might be provided by a change in one or more of the interacting cooperative systems (i.e., a rate-controlling system). In this type of model the three common combinations of developmental levels for the elbow and forearm/racket action of the serve (2, 2; 2, 3; and 3, 3) would be strong attractor movement patterns in the older portion of the life span.

The role of instruction and feedback, and consequently the intention of the performer to change the movement pattern, has not been widely addressed from the dynamic systems perspective. It seems unlikely that the 2 older servers with the most advanced movement patterns were coincidentally tennis teaching professionals. We would hypothesize that instruction/feedback and/or experimentation with movement patterns, perhaps based on observation, could push performers to other attractor movement patterns. The movement pattern used in older adulthood could reflect such an environmental influence as well as the status of the interacting body systems. Many older adult servers pointed out that tennis teaching professionals were not available when they were younger and first learning the game of tennis. This hypothesis must be tested by longitudinal study.

Repetitive practice of skills for many years in adulthood could consolidate the attractor movement pattern and make it more resilient to age-related change than less practiced skills. Change in potentially rate-controlling systems might be slow because the effects of repetitive performance resist change. For example, repetitive performance might help to maintain the flexibility and the strength needed for that movement pattern.

There was some indication here that even in older adulthood more developmentally advanced movement patterns are associated with higher ball impact velocities, although the number of servers at the highest developmental levels was small. Also, greater range of motion was only weakly associated with more advanced movement patterns. Examination of individual subjects, however, also showed that some servers can generate relatively high ball impact velocities (for this age group) using other than the most advanced movement pattern. That is, individuals with somewhat limited flexibility or a moderate developmental level in one body component might compensate with a more effective movement pattern in another component of the serve. The result is that the individual is less disadvantaged compared to his or her peers.

In summary, no significant differences were found between the younger half and older half of the servers observed in movement pattern, ball impact velocity, or static flexibility, although several trends toward decline with advanced age were noted. This suggests that assumptions of rapid decline in the skills of older adults may be incorrect for well-learned and regularly practiced skills. This issue should be explored further with longitudinal studies. No increase in intraindividual variability between the younger and older groups was observed here since all servers were remarkably consistent in the movement pattern used for five serves. Only a longitudinal study could have documented the extent to which present developmental levels and ball impact velocities represent change from higher levels in young adulthood. The absence of significant gender differences suggests that long-term practice has a favorable effect for women in that their performance on this practiced skill was more similar to men's performance than previous studies of a little-practiced but similar skill had demonstrated. Hence, there appear to be benefits from regularly practicing a skill in older adulthood for both men and women, specifically, consistency, maintenance of movement pattern, maintenance of flexibility, and maintenance of ball impact speed.

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