Changes in Spinal Reflexes Preceding a Voluntary Movement in Young and Old Adults

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Background. Age-related differences in spinal excitability during response preparation were assessed by eliciting either a 50% H-reflex or an Achilles tendon reflex preceding the onset of a right plantar flexion contraction in 20 young adults (23.1 ± 1.64 yrs) and 20 old adults (68.5 ± 5.53 yrs).

Methods. On each simple reaction time trial, the test reflex was elicited at a specific test interval during either the foreperiod or the response period. The foreperiod test intervals were 500, 600, 700, 800, 900, and 1000 msec after the presentation of the warning stimulus. The response period test intervals were 50, 100, 150, 200, 250, and 300 msec after the presentation of the response stimulus. Control reflexes were randomly elicited between the simple reaction time trials.

Results. Changes in reflex excitability were not observed during the foreperiod in either age group. During the response period, the percentage of H-reflex facilitation as compared to control was similar for the young (68%) and the old (61%) adults, but the magnitude of Achilles tendon reflex facilitation with respect to control reflex responses was greater in the young adults (74%) than in the old adults (38%). The time course of H- and tendon reflex facilitation was delayed in the old group during the response period.

Conclusions. The results indicate that processes underlying the preparation and generation of a motor response are similar in young and old adults. However, these processes occur at a slower rate in old adults.

Changes in spinal reflexes and cortical potentials preceding the onset of a voluntary movement have been studied in humans to understand the neurophysiology of response preparation (1–3). Cortical potentials occurring prior to voluntary movements have been shown to be different between young and old adults. Specifically, decreases in the amplitude and the slope of the readiness potential and the motor potential have been observed in old adults (4–5). However, the onsets of the readiness potential and the motor potential were not different between the age groups (4). There is also an age-related increase in cortical activity occurring between the readiness potential and the motor potential that might be a possible compensatory mechanism by which older adults attempt to maintain response preparation despite amplitude decreases in movement-related cortical potentials with age (6).

Changes in spinal reflexes during response preparation have not been systematically studied in the old adult. Our current understanding of the aged neuromuscular system would support the hypothesis that age-related preparatory deficiencies are occurring at the spinal level. Slower nerve conduction velocities among old adults (7) may affect the temporal characteristics of response preparation at the spinal level. Conditioned reflex recovery profiles indicate that inhibitory and excitatory influences affecting alpha motorneuron pool excitability are different in young and old adults with respect to the time course and the magnitude of the conditioning effects (8–11). With increasing age, these observed changes in the input-output properties of the aged motoneuron pool may impair the timing and/or effectiveness of supraspinal biasing of reflex excitability that occurs during response preparation (1–3).

In older adults, there are increases in the repetitive discharge force thresholds (12), decreases in derecruitment force thresholds (13), and decreases in discharge rates (14) of motor units. To compensate for these age-related differences in motor unit properties, the modulation and the activation of the alpha motoneuron pool during the preparation and the execution of motor responses may be different in young and old adults. It has been proposed that younger adults may use a movement control strategy involving a coordinated activation of agonist muscles, whereas older adults may favor a coactivation strategy of agonist-antagonist muscle pairs (13). If this is indeed the case, then supraspinal biasing of reflex excitability during response preparation may be greater in young adults as they attempt to selectively activate only the agonist muscles for the impending movement.

The purpose of this study was to identify age-related differences in spinal reflex excitability during response preparation. Achilles tendon reflexes and tibial H-reflexes were evoked preceding a rapid right plantar flexion in young and old adults. This protocol was used to explore spinal responses which might be active in aging adults: (a) to optimize preparation for movement performance; and (b) to compensate for neural and muscular changes that occur with increasing age. Despite some limitations, differences between Achilles tendon reflexes and tibial H-reflexes will allow us to address the role of the gamma motor system in response preparation as a function of age.
METHODS

Subjects and materials. — Changes in spinal reflexes preceding the onset of a right plantar flexion were assessed in 20 young adults (23.1 ± 1.64 yrs) and 20 old adults (68.5 ± 5.53 yrs). The subjects were seated on a custom-built reflex bench with their feet resting on foot plates in series with strain gauges (knee at 120°; ankle at 90°). Surface electromyographic (EMG) responses were recorded from the right soleus muscle. The visual warning and response stimuli were mounted at a distance of 1.2 m and at eye level.

The Achilles tendon reflex was evoked with an electromagnetic solenoid positioned behind the right Achilles tendon. The H-reflex was evoked by stimulating the tibial nerve in the popliteal fossa with a 1 msec transcutaneous pulse generated with a Grass S-44 stimulator in accordance with the methodology outlined by Hugon (15). The EMG response, the isometric plantar flexion force, and the tendon tap force were sampled at a frequency of 2 kHz per channel and analyzed off-line.

Experimental procedure. — During each experimental session, the subject performed 84 reaction time trials. The goal for the subject was to react as fast as possible to the visual stimulus by performing a right plantar flexion. A constant one-second foreperiod was used to optimize the temporal readiness of the subject. When a constant foreperiod is used, it is possible that the subject will begin to anticipate the reaction time stimulus. Catch trials (n = 8), in which only the warning stimulus and reflex stimulus were presented, were used to reduce anticipatory responses.

The first experimental session was practice. On two other days, either the Achilles tendon reflex or the H-reflex was evoked to assess changes in spinal excitability preceding the onset of the right plantar flexion movement. The type of reflex elicited on each test day was randomized among the subjects. On each reaction time trial, the test reflex was elicited at a specific test interval during either the foreperiod or the response period. The foreperiod test intervals were 500, 600, 700, 800, 900, and 1000 msec after the presentation of the warning stimulus. The response period test intervals were 50, 100, 150, 200, 250, and 300 msec after the presentation of the response stimulus. A total of 84 reaction time trials were administered in four blocks of 21 trials (i.e., 7 test interval).

On the Achilles tendon reflex test day, control Achilles tendon reflexes were randomly elicited throughout the reaction time trial blocks. Similarly, on the day that H-reflexes were assessed, 28 control 50% maximum H-reflexes were randomly interspersed among the 84 reaction time trials. Control M-waves and maximum H-reflexes were measured before and after the reaction time blocks on the H-reflex test day.

Data analysis. — All reflex and reaction time trials were collected and displayed on-line to ensure that a proper response was being recorded (1,3,16). The on-line analyses were also used to monitor the amplitude of the control 50% H-reflexes and the force of the tendon taps. Peak-to-peak EMG and peak force were measured on each reflex trial. Total reaction time (interval between the response stimulus and the onset of voluntary force), premotor time (interval between the response stimulus and the onset of voluntary EMG), and motor time (interval between the onset of voluntary EMG and the onset of voluntary force) were used to measure the reaction time response.

RESULTS

Fractionated reaction time components. — The young adults had significantly faster total reaction times, premotor times, and motor times than the old adults across the three testing days (p < .05; Figure 1). These fractionated reaction time data support the assumption that response preparation is
impaired with age, i.e., older adults need more time to prepare their motor responses. The remainder of the data analysis was conducted in an effort to determine the source of the response preparation delays, i.e., age-related differences in the activation of spinal responses prior to the onset of voluntary movement to optimize motor performance.

Control reflex responses. — In both age groups, the EMG amplitudes (as measured by peak-to-peak EMG) of the control Achilles tendon reflex responses did not change across the four blocks of reaction time trials ($p > .05$). The intensity of the mechanical taps to the Achilles tendon was supramaximal, since changes in peak forces of the reflex responses were independent of the tendon tap forces ($r = .01$). Moreover, the tendon tap forces (measured from piezoelectric transducers mounted in series with the solenoid plunger) did not change during the test session ($p > .05$). The EMG amplitudes of the control 50% H-reflexes were also stable and did not change across the four blocks of reaction time trials in both age groups ($p > .05$). More importantly, the EMG amplitudes of the maximum M-waves and the maximum H-reflexes were similar before and after the four reaction time blocks in both age groups ($p > .05$). The EMG amplitudes for the control responses in both age groups and for both reflexes were also reliable as supported by intraclass reliability coefficients greater than $R = .90$. These results indicate that a stable baseline was maintained throughout the testing sessions, and the intensities of the reflex stimuli did not bias the response preparation results.

Achilles Tendon Reflexes and Response Preparation

Foreperiod. — Only slight changes were observed in the amplitude of the Achilles tendon reflex during the foreperiod. Statistical a priori comparisons revealed that for the young group, reflex force was inhibited by 9% at both the 800 and 900 msec test intervals ($p < .05$; Figure 2B). However, no significant changes were observed in EMG amplitude for the young subjects, and no significant changes were observed during the foreperiod for either EMG amplitude or peak force in the older adults (Figure 2).

Response period. — Both age groups exhibited a facilitation of the Achilles tendon reflex during the response period, but the rate of this reflex facilitation was more rapid in the young adults than in the old adults. As seen in Figure 2A, the magnitude of reflex facilitation above baseline scores for the young adults was statistically significant at the 100 msec and 150 msec intervals, while for the older adults Achilles tendon reflex facilitation was statistically significant at the 100, 150, and 200 msec intervals. Furthermore, the facilitation for the young adults at the 100 msec and 150 msec intervals (40% and 74%, respectively) was significantly greater than that for the older adults at these intervals (20% and 29%).

H-Reflexes and Response Preparation

Foreperiod. — There were no changes observed in the magnitude of the H-reflex during the foreperiod for either age group ($p > .05$; Figure 3). However, a qualitative analysis of our individual response preparation profiles during the foreperiod for both our young and old subjects showed large inter-subject variability. Although some subjects showed no change in H-reflex excitability during the foreperiod, other subjects showed inhibition and others demonstrated a facilitation of motoneuron excitability.

Response period. — Similar to the effects observed for the Achilles tendon reflex, both groups exhibited a facilitation of
the H-reflex during the response period, but the onset of this reflex facilitation was more rapid in the young adults than in the old adults (Figure 3A). A priori statistical analyses revealed that there were no changes in H-reflex amplitude for either group at the 50 msec test interval. However, at the 100 msec interval, H-reflex amplitude was augmented for the young adults over control values (32%; $p < .05$); there was no change above control scores for the old adults (15%). Both young and older groups demonstrated similar H-reflex facilitation at 150 msec (68% and 61%, respectively).

**DISCUSSION**

**Age-related differences in response preparation: foreperiod.** — The nature of spinal events during the foreperiod remains equivocal. Although an inhibition of spinal reflexes during the foreperiod was initially reported (17) and supported by subsequent studies (1,18,19), other studies have reported either no change (20-22) or even a facilitation (23-25) of motoneuron excitability during the foreperiod. A more recent publication has concluded that the large interindividual variability of motoneuron excitability during the foreperiod in young adults reflects different movement strategies inherent to individual subjects (26). The lack of age-related differences in spinal reflex excitability during the foreperiod reported here may also reflect the different preparatory sets used by our subjects to optimize their own motor performance. A qualitative analysis of the individual response preparation profiles during the foreperiod for both our young and old subjects showed that some subjects
exhibited no change in excitability, while in other individuals either a decrease or an increase in motoneuron excitability was observed. Thus, it appears that both old and young subjects may adopt varying strategies in preparation for movement.

Age-related differences in response preparation: response period. — Following receipt of the response stimulus, the amplitude of the H-reflex response was similar for young and older adults. Both groups may well be using a similar mechanism to facilitate the motoneuron pool as the response is generated. However, analysis of the H-reflex curves indicates that the onset of H-reflex facilitation is delayed in the older individuals, and this may contribute to the slowing of reaction time with age.

There are likely several possible explanations for the longer latency of H-reflex facilitation in older adults. Slower peripheral motor nerve conduction velocity (7, 27), a reduction in the number of fast-conducting corticospinal tract neurons (28), a decrease in the number of functional motor units (29), alterations in the motor endplate (30), and alterations in the morphological and physiological characteristics of muscle (31, 32) in older adults are deleterious changes in the aged neuromuscular system that may adversely affect the preparation of the motor system for optimal movement performance.

For the Achilles tendon reflex, there were marked differences between subject groups. Indeed, perhaps the most interesting finding involves the observation that tendon reflex facilitation occurred over a more gradual time course and reached lower amplitude in the old adults when compared with the younger individuals. One factor that differentiates H- and tendon reflex responses concerns the nature of the mechanical response that initiates the Ia afferent volley for the tendon reflex. EMG amplitude scores for the control Achilles tendon reflex were similar in both groups (p > .05), even though the older adults in the present study had lower H-reflex amplitudes than the young adults (p < .05). The mechanical stimulus may have excited a greater number of Ia afferents in the old adults because of the increase in muscle stiffness and the decrease in tendon compliance with increasing age (33, 34). Indeed, previous studies have suggested that tendon reflexes can be even greater in older adults than in younger individuals (9).

While gamma motoneuron excitability is not the only variable accounting for the difference between the H- and the tendon reflex (35), it is certainly one possible factor. Alternatively, both young and older adults may activate nonspecific reticulospinal and other nonpyramidal descending fibers, and these other pathways may influence motoneuron excitability during the response period. While the extent of this activation may be similar for both groups, the muscle spindle in the older adults may already be at a high bias level due to passive muscle and connective tissue factors (36), and this may account for lower tendon reflex excitability during the response period in the older adults than in the young subjects (Figure 2).

These data seem to support the notion that the mechanism for generating a motor response is not altogether different in young and old adults. Both subject groups appear capable of facilitating the motoneuron pool prior to the actual movement. However, the profile of motoneuron facilitation is obviously different in older adults: the time course of H- and tendon reflex facilitation is delayed in the older group during the response period (Figures 2 and 3).

Perhaps one explanation is that the younger adults have an appreciable portion of the motoneuron pool that can be facilitated during the response period. However, the older adults execute the rapid motor response with a motoneuron pool that is already under high bias (as demonstrated by the elevated control Achilles tendon reflex). Consequently, the proportion of the motoneuron pool that can be potentiated during the response period is reduced in the older group. The H- and tendon reflex curves during the response period were similar in the young subjects, and were it not for the elevated baseline tendon reflexes observed in old adults, both H- and tendon reflex curves might appear similar in the older group as well.

In support of this concept, the experimental protocol required the assessment of 50% of the control H-reflex value. This leaves an identical proportion of the motoneuron pool that could be facilitated during the response period for both groups. However, supramaximal tendon reflex stimuli recruited a greater proportion of the motoneuron pool in the older adults due to numerous factors (discussed above). Thus, when the voluntary motor response was generated, a lesser percentage of the motoneuron pool was available for potentiation in the older adults than the younger individuals.

In conclusion, the process of preparing to execute a motor response seems to be similar in young and older adults: both subject groups are made up of individuals who are capable of augmenting or diminishing motoneuron excitability during the foreperiod. Moreover, both subject groups also seem to utilize similar strategies to produce a rapid motor response. However, peripheral neuromuscular and central nervous factors seem to modify the time course of response generation. The changes in time course of motoneuron excitability are congruent with the general slowing theory of aging in which the mechanisms of sensorimotor processing are similar in young and older adults, but are produced at a slower rate (37). Thus, the slower reaction times with increasing age observed in this study and previously (38) may not only reflect central processing delays, but the additional time needed to activate a sufficient number of alpha motoneurons to initiate a muscle contraction.

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