Evaluation of Movement Speed and Reaction Time as Predictors of All-Cause Mortality in Men

E. Jeffrey Metter,1 Mathew Schrager,1 Luigi Ferrucci,1 and Laura A. Talbot2

1National Institute on Aging, Clinical Research Branch, Harbor Hospital, Baltimore, Maryland.
2Uniformed Services University of the Health Sciences, Graduate School of Nursing, Bethesda, Maryland.

Muscle power is associated with mortality independent of strength, suggesting that movement speed and coordination convey health-related information. We hypothesized that movement speed is a marker of longevity. Our participants included 1196 men who performed a tapping and/or auditory simple (respond to a sound) and disjunctive (respond to a higher pitched sound) reaction-time tasks while participating in the Baltimore Longitudinal Study of Aging. Mortality was assessed over 40 years. Tapping time was associated with mortality (relative risk [RR] = 1.34 per minute, 95% confidence interval [CI], 1.05–1.70) adjusted for age, and persisted with adjustments for arm strength and power. Simple (RR = 1.17 per 100 ms, 95% CI, 1.03–1.32) and disjunctive (RR = 1.14 per 100 ms, 95% CI, 1.03–1.27) reaction times but not their difference (RR = 1.04 per 100 ms, 95% CI, 0.92–1.19) were associated with mortality after adjustments for age, neurological/psychiatric and neck/arm pain histories. Age-associated impairments in motor control systems but not the decision to move affects longevity.

SARCOPENIA has been identified as an important consequence of aging (1) and a strong risk factor for disability and mortality. The etiology of sarcopenia is known to be multifactorial and its clinical manifestations include the decline of muscle mass, muscle strength, and muscle power (2,3). Age-associated differences have been identified in many neuromuscular factors that may be implicated in the development and consequences of sarcopenia, including declines in arm strength and cranking power (4), changes in muscle fiber composition (5,6), muscle quality (7), slowing of movement and reaction times (8), motor unit recruitment patterns (9), and declining function of basal ganglia (10) and cerebellar systems (11).

Muscle power seems to be a better predictor of disability and mortality than do muscle strength and mass (12,13). Studies have shown lower mortality in stronger individuals (14–17), independent of body mass (16), and muscle mass (17). The effects of muscle strength and power on mortality may not be direct, but rather mediated through effects on functional capability (18,19), disability, and frailty (20).

Recently, we reported that muscle power, measured in an arm-cranking task, was a predictor of mortality independent of arm muscle strength, while adjusting for muscle mass, physical activity, and body size (13). Of particular interest was the finding that muscle power was a predictor of mortality even when power was generated against low work loads, where maximal power levels are not generated but where rapid repetitive movements are required. These observations suggested that motor coordination and speed are important independent predictors of mortality.

However, the arm-cranking task was dependent on maximizing speed against specific workloads, and was not primarily a speed task. This study addresses whether movement speed or reaction time are risk factors for mortality, independent of variables traditionally used to describe sarcopenia, including muscle strength, muscle power, and muscle mass. We hypothesized that delayed movement speed during a repetitive task predicts mortality, and that this effect differs from performance on simple and choice reaction times that are dependent on the decision to move.

METHODS

Study Population

Our participants consisted of 1196 male participants in the Baltimore Longitudinal Study of Aging (BLSA) (21) who had either tapping or reaction time measurements performed during at least one of the study visits. The participants were self-volunteered and examined every 1–2 years. They were well educated and considered themselves well off and healthy. No specific health selection criteria were used to screen participants whose data are included in this analysis. Medical diagnoses were reviewed, and 19% of participants, prior to their last testing date, had a neurological and/or psychiatric diagnoses (International Classification of Diseases, Revision 9 [ICD9] codes 290–360, including depression, multiple sclerosis, parkinsonism, dementia, chronic brain syndrome, psychosis, tremor, carpal tunnel syndrome, peripheral neuropathy, hemi- or paraplegia, seizure with exclusion of anxiety, conversion reactions, impotency, alcohol or smoking abuse, headache, Bell’s and congenital facial palsy, trigeminal neuralgia, and focal neuropathies not involving the arm), and 4% had a stroke history. In addition, answers to two health questions at each visit regarding neck and arm pain indicated that 37% of
participants complained of neck or arm pain on at least one evaluation.

**Measurements**

**Tapping test.**—The tapping test was introduced into the BLSA to evaluate alternate pencil taps between two targets (21), to evaluate Fitts' Law, i.e., the time required to acquire a target is a logarithmic function of the distance to the target when size is constant (22).

For this study, the only data utilized were from the control state, which required tapping into a single circle rather than between two targets. Participants were asked to tap 100 times in a target circle, holding a pencil and keeping their hand at 1–2 cm, 5–10 cm, and 10–15 cm above the paper on subsequent trials. A card (held by the tester) next to the paper acted as a visual cue for the appropriate height. The tester used a stopwatch, and visually counted the number of taps. The test was administered from 1961 through 1981.

The tapping time reflects the speed at which the participant could move his hand at the wrist, elbow, and shoulder. The movement requires motor control to stabilize the wrist, elbow, and shoulder, and to rapidly move the forearm and/or wrist upward and downward.

Comparing the tapping times from the three hand heights revealed: a) a modest correlation between the 1–2 cm and the other two measures ($r = 0.34$ and 0.36, $p < .0001$) and b) a very strong correlation between 5–10 cm and 10–15 cm ($r = 0.94$, $p < .0001$). Because the three tapping times should reflect similar movement patterns, and because there was only modest correlation between the 1–2 cm and the other two measures, we chose to sum the three values and consider it as the best representation of tapping performance.

**Reaction time.**—Reaction-time measures were assessed under a simple condition where the participant pressed a button whenever hearing a beep, and under a disjunctive condition where he pressed the switch when hearing the higher pitched of two tones. Although the two reaction-time responses require movement, the movement is simpler than with the tapping task. The response is more dependent on the response time to an auditory stimulus and to a lesser extent on the speed of movement itself. The difference between the disjunctive and simple reaction time reflects the central processing required to make a decision based on the auditory tone.

The reaction-time methodology was previously described by Fozard and colleagues (8). Participants were seated in a well lit, ventilated, soundproof booth. They were initially tested to be certain that they could easily hear the 1000 and 250 Hz auditory signals at either 56 or 62 dB. The stimulus tones were presented for 3 seconds during practice trials, and for 0.3 seconds during testing. Participants responded to the auditory stimuli by pressing a handheld response button as quickly as possible. In the simple task, they were instructed to press the button for all auditory stimuli and, for the disjunctive task, they were told to press the button for the higher pitched tone. Stimuli were presented according to a single random order of variable interstimulus intervals ranging from 6 to 13 seconds. One hundred twenty-two trials were presented in 4 blocks, which took approximately 5 minutes each. Time represents the median reaction time for those responses where the participants made an appropriate and correct decision, for the final 20 trials for the simple reaction time, and for the last 26 trials for the disjunctive task. Response reaction times were considered appropriate if they were longer than 150 ms and less than 800 ms. The 150 ms to 800 ms window was selected with the rationale that times greater than 800 ms implied that a response was not being made, and that a time less than 150 ms represented an anticipatory response (8). The reaction time data were collected from 1973 through 1991.

**Muscle power.**—Power was measured by arm cranking using a bicycle that was converted to act as a driveshaft to power a calibrated automobile generator as previously reported (4,13,23). Participants performed a maximal effort for 10–15 seconds at each of 4 load settings (1, 2, 3, and 4 amps). The maximum scale reading was converted to power units by a calibration curve. Because the patterns of change in power for the 4 loads with age were identical when normalized to 20-year-olds (4), as were the risks associated with all-cause mortality (13), a single measure, total power, was calculated as the sum of the power generated against the four workloads.

**Isometric muscle strength.**—Isometric strength was tested, as previously reported, with participants seated with the upper arms perpendicular to the floor and the forearms parallel to the anterior–posterior axis and perpendicular to the head-to-seat axis (4,13). Grip strength was measured with a Smedley Hand Dynamometer (Stoelting, Wood Dale, IL) calibrated to known weights and adjusted to fit each participant’s grip (17). Total strength scores were calculated by summing the eight arm measurements and both grip strengths.

A small systematic drift in the power and strength data was observed by year, and was adjusted by regressing power and strength by date to obtain predicted values (4). The predicted values were subtracted from the average predicted value from 1958 through 1962 and then added to the actual measurement for the visit. The resulting corrected data no longer had a significant correlation with the date.

**Leisure Time Physical Activity (LTPA).**—LTPA was self-reported based on the amount of time spent in 97 activities since the last visit (24) expressed as minutes per day. The intensity of the reported activities was converted to metabolic equivalents (METs) based on published values in the literature, which were established in healthy younger adults and described by Talbot and colleagues (24). One MET approximates resting energy expenditure, 3.5 ml/kg per minute. LTPA for each reported activity was then converted into MET-minutes by multiplying the minutes reported for the activity by the MET value assigned to that activity and adjusting to a 24 hour day.

The activities were then grouped and totaled based on their MET levels. Low intensity LTPA included activities requiring an energy expenditure of <4 METs; moderate intensity LTPA included those activities requiring between
Muscle mass, weight, and height.—Total body muscle mass was estimated using 24-hour creatinine excretion by standard clinical procedures as previously described (21). Muscle is estimated to be 17–20 kg of whole wet mass per gram of urinary creatinine. Height and weight were measured at each visit. Weight was measured to the nearest 0.1 kg and height to nearest 0.1 cm. Body mass index (BMI) was calculated and used to estimate body size.

Assessment of mortality.—Deaths were determined by intermittent telephone follow-up on inactive participants, correspondence from relatives, and annual searches of the National Death Index up to 2000.

Statistical Analysis of the Data

Differences in baseline characteristics between survivors and decedents were assessed by Student t tests, while chi-square tests were applied to compare percentages. Descriptive data are expressed as mean ± standard deviation (SD) unless otherwise stated. For all analyses, a two-tailed p value <.05 was used to indicate statistical significance. All analyses were performed using S-PLUS software (version 6.2; Insightful, Seattle, WA).

The tapping and reaction time tests were assessed at the same visit on only 1122 occasions. For this reason, separate analyses were performed for the tapping tests and reaction times using different subsets of the BLSA sample.

Proportional hazards analysis was used to determine the longitudinal contribution of tapping and reaction times on mortality using the survival functions developed by Therneau (25). Time-dependent covariates in the longitudinal analyses used the Anderson–Gill formulation as a counting process. For each participant, time was divided into intervals between evaluations, and the covariates were based on the evaluation at the start of the interval. Thus, the independent variables can increase or decrease over time. Proportionality of the hazards was tested by plotting the Schoenfeld residuals against a log function of time using cox.zph in S-PLUS version 6.2. Data stratification on time and introduction of a time-dependent variable (with time expressed as a log function) are two approaches that were explored to deal with lack of proportionality (25).

The tapping test and the muscle arm-cranking and strength measures were not routinely collected on the same visits, with 48% missing data. To explore the relationships between tapping time, muscle strength, and power on mortality, we searched for patterns of missing data (26). First, arm strength and arm-cranking power were missing together. This occurred because the two tests were performed at the same session. Second, the strength and power measurements were stopped in 1985, whereas the tapping test continued until approximately 1991. Third, for scheduling reasons, the tests were often not scheduled at the same visit. In general, the pattern of missing data appeared to be noninformative, although more participants might be censored in the missing group. Missing data were imputed using the regression approach described by Harrell (27, pages 41–52) using his S function transcan, with imputation using fit.mult.impute to obtain five imputations for proportional hazard analyses. The imputed results were compared to results obtained by eliminating missing cases.

RESULTS

Tapping Time

The relationship between tapping time and mortality was assessed from 4637 measurements in 921 men. Descriptive characteristics of the participants are presented in Table 1. The average length of follow-up was 22.7 (9.8) years with 506 deaths over the follow-up period. Tapping time and simple and disjunctive reaction times increased with age (r = 0.18, 0.26, and 0.36, respectively; p < .0001) (Figure 1).

Increasing tapping time was associated with an increased risk of death (relative risk [RR] = 2.97, 95% confidence interval [CI], 2.31–3.83), controlling for age (RR = 1.34 per minute, 95% CI, 1.05–1.70), and when controlling for age, neurological/psychiatric disease, stroke, and neck/arm pain (RR = 1.35, 95% CI, 1.06–1.72). The effect of tapping time (RR = 1.51, 95% CI, 1.09–2.08 per minute) on mortality persisted with further adjusting for BMI, muscle mass, and physical activity levels.

However, there was a clear lack of proportionality over time as seen by plotting the Schoenfeld residuals against a log function of time. Risk decreased over the first 10 years of observation, and then remained constant over the subsequent years of follow-up. To deal with the time-dependent effect, the analysis was stratified with separate analyses over the first 10 years, and over the subsequent years while controlling for age (Table 2). A significant risk was associated with increasing tapping times over the first 10 years of follow-up when adjusting for age, but not in subsequent years.

The declining risk associated with increasing tapping times to follow-up prompted further investigation to de-
termine if the observed effect was driven by gravely ill participants in their terminal stage of life. Tapping time continued to be a significant predictor of mortality when only the participants who had survived at least 5 years following their last assessment were included in the analysis.

**Impact of Muscle Strength and Power**

Muscle strength and power are independent predictors of all-cause mortality. Strength and power were not collected on the same schedule as was tapping in the BLSA, producing 48% missing strength and power data. Data on strength, power, and tapping time were available from 1969 observations from 709 men. Two methods were used to examine the relationship of mortality to strength, power, and tapping. First, imputation was used to estimate missing values for visits where all three measurements were not available. Second, the data set was reduced to the 1969 visits where all three measurements had been tested. The relative risks from the resulting models, which include a time-dependent term for tapping time, are shown in Table 3. The risk associated with longer tapping times was similar across the 4 models for both approaches to handling the missing data, suggesting that the impact of tapping is, at least in part, independent of either strength or power.

**Reaction Time**

Reaction time data were available from 985 men who had 2789 evaluations and 480 deaths during follow-up. Both simple and disjunctive reaction times and their difference were associated with all-cause mortality, but not after adjustment for age. However, with additional adjustments for neurological/psychiatric diagnoses, neck/arm pain, BMI, and physical activity increasing simple and disjunctive reaction times showed an increase mortality risk, which was not present for the difference between the two (Table 4). The increase risk persisted with further adjustments for BMI and physical activity. As with tapping time, there was a lack of proportionality over time, with risk decreasing over the first 10–15 years of observation. To deal with the time-dependent effect, the analysis was stratified with separate analyses over the first 10 years, and over the subsequent years while controlling for age (Table 4). An increasing simple or disjunctive reaction time, but not the difference between them, was associated with increased risk over the

<table>
<thead>
<tr>
<th>Table 2. Risk Ratios for Tapping Time and All-Cause Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Ratio</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td><strong>Entire follow-up period</strong></td>
</tr>
<tr>
<td>No. of participants/evaluations</td>
</tr>
<tr>
<td>Tap time, min</td>
</tr>
<tr>
<td><strong>Follow-up of the first 10 years</strong></td>
</tr>
<tr>
<td>No. of participants</td>
</tr>
<tr>
<td>Tap time, min</td>
</tr>
<tr>
<td><strong>Follow-up from 10 years and later</strong></td>
</tr>
<tr>
<td>No. of participants</td>
</tr>
<tr>
<td>Tap time, min</td>
</tr>
</tbody>
</table>

Notes: Numbers in parentheses are 95% confidence intervals. Models were adjusted for age.

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Figure 1. Age-associated differences in tapping (A), and simple (B), and disjunctive reaction times (C). Each plot includes all available data and a LOESS regression line. Tapping time is the time taken to tap the tip of a pencil 100 times in a circle. Simple reaction time is time to activate a button on hearing a tone, whereas disjunctive reaction time is the time to activate the button when hearing the higher pitched of two tones.
first 10 years when adjusting for age and other covariates, but not in subsequent years.

**DISCUSSION**

In this study, increasing tapping time was found to be associated with increasing mortality. The effect of tapping time on mortality was independent of the effects of muscle power and strength. Both increasing simple and disjunctive reaction times were associated with increasing mortality only with further adjustments beyond age, particularly neurological/psychiatric diagnoses and neck/arm pain history. A significant association of increasing reaction time for both simple and disjunctive tasks but not for their difference suggests that the movement part of the task is related to mortality. The difference between the simple and disjunctive tasks represents the central processing involved with the decision to make the movement based on the auditory tone, and was not related to mortality. These observations suggest that the ability to make rapid movements, but not the decisional task in distinguishing between two signals, is a marker of longevity.

In previous work, an arm-cranking power task was an independent predictor of mortality whether examining maximal power or power generated against a small load where the power generated was mostly dependent on the speed of movement (13). Power tests reflect several aspects of muscle function that control both force generation and the velocity of movement. Josephson (5) noted that factors important for power generation during cyclic movements include the muscle velocity and force-velocity relationship, the muscle length–tension relationship, and the pattern of muscle activation. Although these factors are important for

**Table 3. Mortality Risk Ratios for Tapping Times When Adjusted for Strength and Power**

<table>
<thead>
<tr>
<th>Imputation of missing data</th>
<th>Tapping (min)</th>
<th>Tapping, Strength (kg)</th>
<th>Tapping, Power (kg*m/min)</th>
<th>Tapping, Strength, Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants/evaluations</td>
<td>921/4639</td>
<td>921/4639</td>
<td>921/4639</td>
<td>921/4639</td>
</tr>
<tr>
<td>Tapping</td>
<td>2.16 (1.81–2.57)</td>
<td>2.15 (1.66–2.78)</td>
<td>2.09 (1.70–2.58)</td>
<td>2.14 (1.63–2.80)</td>
</tr>
<tr>
<td>Strength</td>
<td>0.95 (0.93–0.98)</td>
<td>0.98 (0.95–0.995)</td>
<td>0.97 (0.95–0.99)</td>
<td>0.99 (0.98–0.996)</td>
</tr>
<tr>
<td>Power</td>
<td>0.98 (0.97–0.99)</td>
<td>0.98 (0.97–0.99)</td>
<td>0.99 (0.98–0.996)</td>
<td>0.99 (0.98–0.996)</td>
</tr>
<tr>
<td>Time*tap</td>
<td>0.65 (0.57–0.74)</td>
<td>0.66 (0.57–0.75)</td>
<td>0.65 (0.57–0.74)</td>
<td>0.65 (0.57–0.75)</td>
</tr>
<tr>
<td>Tapping</td>
<td>1.62 (1.19–2.21)</td>
<td>1.54 (1.13–2.09)</td>
<td>1.51 (1.11–2.06)</td>
<td>1.50 (1.10–2.03)</td>
</tr>
<tr>
<td>Strength</td>
<td>0.98 (0.96–0.998)</td>
<td>0.99 (0.97–1.01)</td>
<td>0.99 (0.97–1.01)</td>
<td>0.99 (0.98–1.00)</td>
</tr>
<tr>
<td>Power</td>
<td>0.99 (0.98–0.998)</td>
<td>0.99 (0.98–1.00)</td>
<td>0.99 (0.98–1.00)</td>
<td>0.99 (0.98–1.00)</td>
</tr>
<tr>
<td>Time*tap</td>
<td>0.56 (0.50–0.63)</td>
<td>0.86 (0.83–0.88)</td>
<td>0.86 (0.83–0.88)</td>
<td>0.86 (0.83–0.88)</td>
</tr>
</tbody>
</table>

Notes: The four columns represent different models that were tested. Each model included a time-dependent tapping covariate, and the variables listed at the head of the column. Rows are the individual variables, with cells showing risk ratios when the variable is included in the corresponding model. Imputation used imputation to handle missing data. Reduced sample eliminated missing data.

All models were adjusted for age. Time*tapping time = ln(time+1)*tapping time.

Strength is per 10 kg.

Power is per 100 kg/m/min.

**Table 4. Mortality Risk Ratios for Reaction Time With and Without Adjustments**

<table>
<thead>
<tr>
<th>Model Covariates</th>
<th>Number of Measurements</th>
<th>Simple Reaction Time (/100 ms)</th>
<th>Choice Reaction Time (/100 ms)</th>
<th>Difference (/100 ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire follow-up period</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>2789</td>
<td>1.66 (1.47–1.88)</td>
<td>1.64 (1.49–1.81)</td>
<td>1.46 (1.26–1.68)</td>
</tr>
<tr>
<td>RT, age</td>
<td>2789</td>
<td>1.11 (0.98–1.22)</td>
<td>1.10 (0.99–1.22)</td>
<td>1.05 (0.93–1.19)</td>
</tr>
<tr>
<td>RT, age, hx</td>
<td>2644</td>
<td>1.17 (1.03–1.32)</td>
<td>1.14 (1.03–1.27)</td>
<td>1.04 (0.92–1.19)</td>
</tr>
<tr>
<td>RT, age, hx, bmi, ltpa</td>
<td>2039</td>
<td>1.20 (1.03–1.39)</td>
<td>1.13 (0.99–1.27)</td>
<td>1.00 (0.85–1.19)</td>
</tr>
<tr>
<td>Follow-up of the first 10 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>1573</td>
<td>1.88 (1.62–2.17)</td>
<td>1.98 (1.68–2.32)</td>
<td>1.32 (1.04–1.66)</td>
</tr>
<tr>
<td>RT, age</td>
<td>1573</td>
<td>1.30 (1.11–1.51)</td>
<td>1.31 (1.09–1.59)</td>
<td>1.03 (0.87–1.24)</td>
</tr>
<tr>
<td>RT, age, hx</td>
<td>1512</td>
<td>1.39 (1.20–1.61)</td>
<td>1.34 (1.10–1.63)</td>
<td>0.98 (0.81–1.19)</td>
</tr>
<tr>
<td>RT, age, hx, bmi, ltpa</td>
<td>1222</td>
<td>1.39 (1.14–1.70)</td>
<td>1.23 (0.98–1.56)</td>
<td>0.97 (0.64–1.48)</td>
</tr>
<tr>
<td>Follow-up from 10 years and later</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>1216</td>
<td>1.46 (1.23–1.73)</td>
<td>1.53 (1.35–1.74)</td>
<td>1.55 (1.29–1.85)</td>
</tr>
<tr>
<td>RT, age</td>
<td>1216</td>
<td>0.96 (0.79–1.15)</td>
<td>1.06 (0.93–1.21)</td>
<td>1.15 (0.96–1.35)</td>
</tr>
<tr>
<td>RT, age, hx</td>
<td>1132</td>
<td>1.01 (0.84–1.22)</td>
<td>1.11 (0.97–1.28)</td>
<td>1.18 (0.99–1.41)</td>
</tr>
<tr>
<td>RT, age, hx, bmi, ltpa</td>
<td>817</td>
<td>1.15 (0.91–1.44)</td>
<td>1.15 (0.97–1.38)</td>
<td>0.85 (0.59–1.23)</td>
</tr>
</tbody>
</table>

Note: The rows represent different models. Difference = Choice Reaction Time – Simple Reaction Time; RT = reaction time; hx = neurological, stroke and neck/arm pain history; bmi = body mass index; ltpa = leisure time physical activity.
power, they appear less important for the rapid movements observed with the tapping task. Strength and power do not appear to be critical for a simple tapping movement. The simple tapping movements are more directly dependent on the motor coordination for a simple repetitive movement. The observations from this study suggest that this movement is controlled somewhat differently than for the arm cranking, as each had independent effects on mortality. The observations suggest that different components of movement execution independently and differently impact on health, disease, and ultimately longevity.

We previously argued that well coordinated movements are required to optimize an arm-cranking power task, and suggested that coordination of motion by the nervous system was critical in the causal pathway between muscle power and mortality (13). The independent relationship between the tapping task and mortality when controlling for arm strength and arm power (Table 4) suggests the importance of multiple components of motor control on health and longevity. The control of movement is performed by the interaction of several neural systems including the cortical motor cortex, the basal ganglia, and the cerebellum, the activities of which are modulated by spinal reflex loops and sensory inputs. Aging in the extrapyramidal system, particularly the dopaminergic systems, is likely key in the age-associated loss of motor speed and power, as age-associated declines in pigmented cells and dopaminergic content begin in the third decade of life in the substantia nigra, basal ganglia, and cortical regions to which they project (28, 29). In addition, patients with Parkinson’s disease demonstrate a decline in movement (referred to as bradykinesia) and in motor speed (30) that accompanies the degeneration of the dopaminergic pathway arising in the substantia nigra. Diminished function of the dopaminergic system is associated with declines in movement aging animals (31). Such declines have been argued to cause the slow, progressive decline in habitual physical activity with increasing age that occurs in many species (32).

Parkinson’s disease may represent a reasonable model to understand the relevance of our findings. The slowness and poverty of movement in Parkinson’s disease has been argued to result from deterioration in the basal ganglia output which supplements cortical mechanisms in preparing and completing movement (33). One likely result of the deterioration is an increased demand on cortical mechanisms to initiate and execute the movement. The result is a less efficient control of movement. Imaging studies—showing decreased activation with movements in midline motor areas, but increased activity in lateral frontal motor areas—are consistent with these observations. Somewhat similar observations have been made in healthy older participants. Ward and Frackowiak (34) found that during a submaximal handgrip task, older participants showed increased cortical activation by functional magnetic resonance imaging in motor regions than did younger participants. Mattay and colleagues (35) found similar increases in cortical activation in elderly persons with a finger-tapping task. The patterns of motor changes in Parkinson’s disease may be an exaggerated model of what occurs with normal aging.

In relationship to mortality, Parkinson’s disease is associated with a shortened life expectancy. Treatment can and does improve survival (36–38), with the risk related to the presence of extrapyramidal symptoms, particularly bradykinesia (37). Taken together, the age-associated changes that occur in the basal ganglia, the characteristic features of Parkinson’s disease, and the associated increased mortality with Parkinson’s disease suggest a relationship between our findings and the organization of movement by the central nervous system. At one level, the aging basal ganglia may account for what we have observed.

The reaction-time tasks were related to mortality only when ignoring age, to which they were correlated, or when adjusted for neurological/psychiatric diagnoses and neck/arm pain histories. Controlling for neck/arm pain appeared to be of greater importance than controlling for neurological/psychiatric diagnoses. Neck/arm pain may limit the movement characteristics of the task to a greater degree than the cognitive components. This finding would be consistent with the risk being associated with both the simple and disjunctive task, but not with their difference. Welford (39) noted that the time taken during the premotor planning is in general far longer than the movement time. Reaction times are on the order of several hundred milliseconds, and get longer with increasing age (8). The adjustment for pain and neurological conditions may reduce the variability across participants and time on performance in the task. This would likely affect the movement part of the task to a greater extent than the decisional part of the task. The major determinants have to do with hearing the tones and either noting when the sound appears or deciding upon its pitch. The decisions required were very simple, and are not likely to be complex enough to discriminate different levels of risk, as observed by the lack of an effect of the difference between the simple and disjunctive task. The observed relationship between the two reaction-time tasks and mortality argue that the decisional aspects of the reaction-time task are not as important as other aspects of movement control and the movement itself.

One possible explanation of our analysis is that, as participants age, they develop multiple diseases, disability, and frailty; the burden of morbidity (not its functional consequence) is the true cause of excess mortality. However, in our analyses, the effect of tapping and reaction times (with adjustments for neurological/psychiatric diagnoses and neck/arm pain) on mortality persisted when only participants who survived at least 5 years after the last measure were included in the analysis. This analytical approach controls for the effects of terminal illness. Furthermore, the effect of tapping time on longevity persisted with adjustments for neurological/psychiatric disorders and for neck/arm pain which could affect movement speed.

A related observation was that the effects of both tapping and reaction times were nonproportional and declined over time. Stratifying the data found a significant effect for both tapping and reaction times prior to 10 years of follow-up on mortality, but not after that period of observation. Both tapping and reaction time association with mortality were over only the first 10 years following the measurement and were not long-term. The presence of declining risk over time is not unusual for risk factors, and can be dealt with using time-dependent covariates, as done here, or alternative
survival models. The implication is that, although movement speed and coordination (as represented by the measures tested here) contribute to mortality, other factors become of far greater importance over time.

This report addresses findings only in men. The BLSA began to study men in 1958 and women in 1978. In preparing this report, we found that only 137 women had had tapping data, and there was no association between tapping time and mortality. The major issue was whether the data collected in women was adequate to actually address the research questions. Our belief was that the data was underpowered to detect a difference of the magnitude observed in the men. To demonstrate this, using the approach suggested by Therneau and Grambsch (25, page 62), the power to detect a risk ratio of 1.4 for tapping time when divided at the median was less than 0.4 with the 37 deaths observed in the women, whereas the power was greater than 0.9 for the men with 507 events. For this reason, we have restricted our report to men.

In summary, both tapping-time tasks and reaction-time tasks were found to be risk factors for mortality. The tapping task was shown to be a risk independent of muscle strength and power. The observations suggest that central nervous system changes that occur in motor control with aging may have important implications for longevity.

ACKNOWLEDGMENTS

Our research was completed in the Intramural Research Program of the National Institute on Aging.

Address correspondence to E. Jeffrey Metter, MD, National Institute on Aging, 3001 South Hanover Street, Baltimore, MD 21225. E-mail: MetterJ@nrd.nia.nih.gov

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