

Age-Related Patterns of Fine Motor Performance across the Adult Lifespan in a Large Population-Based Study

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INTRODUCTION

Fine motor function, which integrates motor control and cognitive processing, has emerged as a promising non-invasive marker for neurodegenerative diseases and cognitive impairment.[1] However population-based reference data on fine motor patterns across adulthood are limited, making it difficult to distinguish physiological aging from pathological decline. The population-based Cooperative Health Research in South Tyrol (CHRIS) study, includes detailed assessments of fine motor function using digital spiral analysis (DSA).[2,3] DSA is a scalable and valid approach that captures the dynamics of hand drawing movements. It enables the quantification of multiple dimensions of fine motor control by extracting a range of spatiotemporal and frequency-based features from the drawing. These features provide a rich, multidimensional profile of neuromotor performance and hold promises for capturing early age-related deviations or subtle motor impairments associated with neurodegenerative processes.

OBJECTIVES

The objectives of this investigation were to characterize normative, age-dependent patterns of fine motor function across adulthood using spiral-derived kinematic metrics. Specifically, we aimed to estimate age-, sex-, and hand-specific centile curves for multiple motor parameters using flexible distributional modelling that captures central tendency, variability, and skewness. In addition, we sought to identify age of peak performance, inflection points in motor trajectories, and the age of steepest decline through derivative-based analysis.

METHODS

All participants from the CHRIS study who completed three digital spiral drawings per hand (six in total) by alternating hands at each repetition were included in this investigation. Five spiral-derived metrics were analyzed, representing distinct domains of fine motor function: spatial properties (trace length), temporal measures (drawing time), kinematic features (drawing speed and acceleration), and markers of movement irregularity (tremor amplitude estimated from pen displacement and deviations from the ideal spiral path). Separate models were fitted for dominant and non-dominant hands, and all models incorporated sex-specific smooth age trends to account for biological differences in motor aging.

To characterize age-normative patterns, the mean and degree of dispersion of each metrics were modeled as functions of age using the Box-Cox Cole and Green (BCCG) distribution within the Generalized Additive Models for Location, Scale, and Shape (GAMLSS) framework.[4] This approach enabled estimation of age-dependent centile curves for each metric while simultaneously modeling changes in dispersion and skewness. The BCCG distribution estimates three parameters: the median (μ), the coefficient of variation (σ), and the skewness (ν). To allow for greater distributional flexibility, we also fit models using the Box-Cox Power Exponential (BCPE) distribution, which includes a fourth parameter to capture kurtosis (τ). Improvements in model fit were evaluated using Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and visual diagnostics.

To further characterize the shape and timing of age-related changes, we conducted inflection point analysis based on the fitted μ (median) curves. First and second derivatives were

computed to identify key ages of interest, including the age of peak performance, the inflection point (change in curvature), and the age of steepest change (maximum slope). This analysis complements centile modeling by highlighting potential transition points or acceleration peaks in fine motor decline.

As a sensitivity analysis, we repeated the modeling using only the second spiral drawing from each participant to minimize potential practice or fatigue effects.

RESULTS

A total of 8,707 participants (53.6% female) aged 18 to 94 years (mean = 44.8, SD = 16.7) returned 6 valid spirals. After exclusion of a minority of spirals with inconsistent metrics, there were 50,299 valid spirals for the analysis. Across all spiral-derived metrics, the BCCG distribution provided evidence of better fit than the normal distribution, effectively capturing age-related skewness in motor performance. The BCPE distribution further improved fit for selected metrics, namely spiral length and tremor amplitude, by modelling excess kurtosis. Model comparisons using AIC and BIC consistently favored flexible models. Derivative-based inflection point analysis identified distinct phases of motor change, with peak performance typically occurring in the late 30s to early 40s and accelerated decline between ages 60 and 70. For example, centile modeling of tremor amplitude (mm) at peak performance age 40, mean dominant hand values were 0.15 for males and 0.14 for females (5th–95th percentile: 0.08–0.33 and 0.07–0.30, respectively); by age 65, medians rose to 0.25 and 0.24, with broader ranges of 0.12–0.72 and 0.11–0.70, reflecting increased tremor and variability with age (Figure). These patterns remained consistent across sensitivity analyses supporting the robustness of the estimated age trends.

CONCLUSIONS

Digital spiral analysis revealed age-normative patterns of fine motor function across adulthood, with peak performance during advanced young adulthood and accelerated decline after age 60. Flexible GAMLSS modelling effectively captured age-related changes in central tendency, variability, and skewness across metrics, by sex and dominance of the drawing hand. These sex-age-specific centile curves offer a robust normative reference for evaluating fine motor performance and may support future applications in the early detection of motor dysfunction and neurodegenerative disease.

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Centile Curves for Tremor amplitude

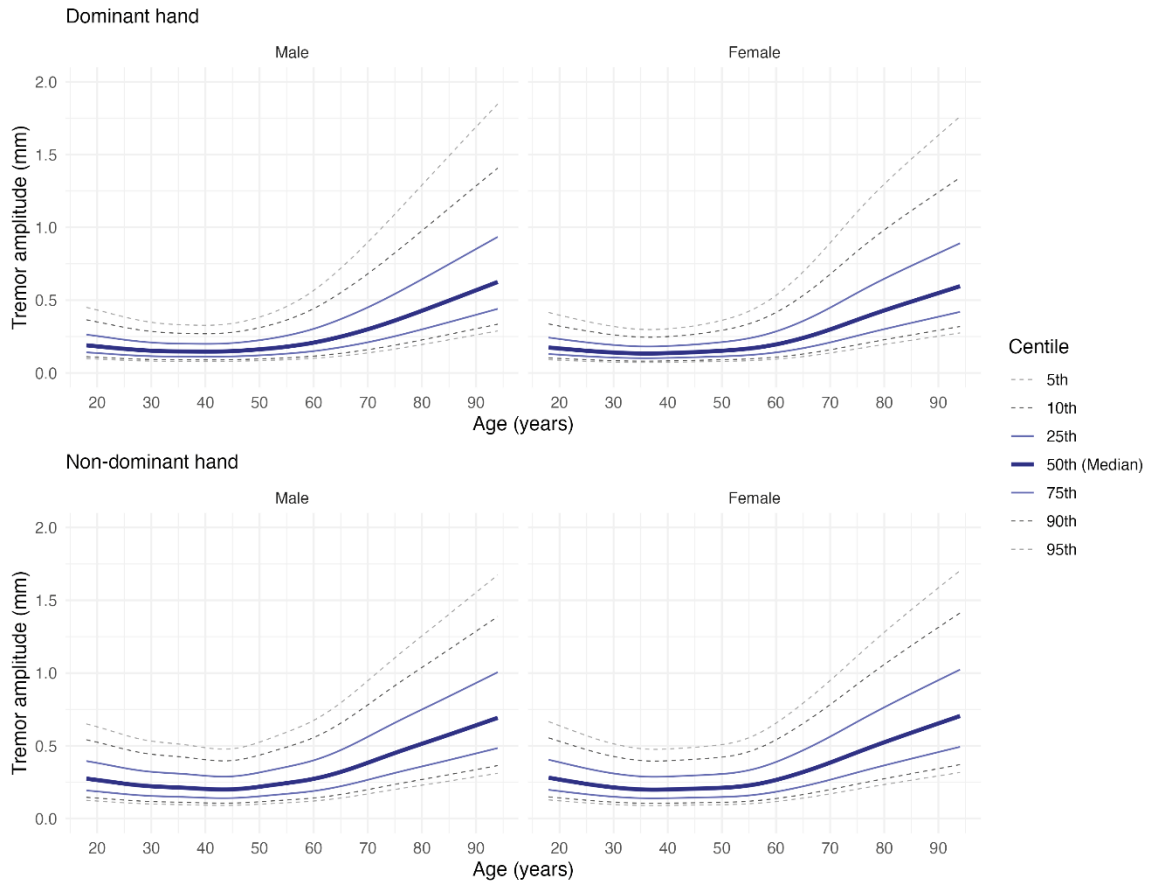


Figure. Continuous age centile curves for tremor amplitude, by sex and drawing hand