5. Results

The Results section of this dissertation thesis can be divided into two parts. The first part contains analyses concerned with the examination of age and sex differences in the amount, trends, and interrelationships of processing fluctuations in postural control on three different time-scales (i.e., moment-to-moment, trial-to-trial, and day-to-day). Group differences in the amount of processing fluctuations and the interrelationships between different types of processing fluctuations were analyzed with analyses of variance (ANOVAs) or analyses of covariance (ANCOVAs). Trends and possible age differences in these trends were analyzed with multi-level models (MLMs). The second set of analyses investigates age and sex differences and potential age by sex interactions in the strength of within-person couplings between day-to-day processing fluctuations in postural control and spatial working memory. Within-person correlations are presented first for descriptive purposes, statistical tests based on multi-level models are conducted thereafter. Between-group analyses of variance and covariance were conducted with the SPSS-software package (SPSS 12.01 for Windows). Multi-level models were conducted with the PROC MIXED procedure implemented in SAS (SAS 9.1 for Windows). The alpha level corresponding to Type I error was set to .05 for all analyses. The sample sizes in the between-group contrasts were rather small. Therefore, *p*-values that were in the range of > .05 and < .1 are reported as being marginally significant. In ANOVA types of analyses, effect sizes are presented with partialed eta squares values (η_p^2) that relate the amount of explained variance by the factor to the residual error variance. In multi-level model analyses, the computation of effect sizes is difficult because the total variance is partioned in several variance components (e.g., within-person variance, between-person variance, and error variance). As a consequence, statisticians have yet to agree on a standardized measure of effect size (c.f., Singer & Willet, 2003). In some applications of multi-level models, pseudo-R^2 statistics are used to quantify the incremental variance in the dependent variable that is predicted by adding a new set of predictors to a given model. However, due to the explicit links between the parts of the model, an additional predictor at a given level might reduce the estimated residual variance at that level but might increase the estimated residual variances at the other levels (Snijders & Bosker, 1999). This situation leads to a negative estimate of the pseudo-R^2 statistic. Therefore, estimates of effect sizes are only reported in ANOVA types of analyses.

The less-known statistical assumptions of multi-level models that have to be met to assure unbiased results were introduced in the Methods section (Section 4.5.1.). Thus, the section below only briefly discusses the more common statistical assumptions of ANOVA types of analysis.

5.1 Statistical Assumptions of the Analysis of Variance and Covariance

The current dissertation employed ANOVAs and ANCOVAs analyses to test the various hypotheses regarding age and sex differences in processing fluctuations. These methods require independent observations on the between-person level and linearity in the examined relationships. The first assumption was guaranteed by study design (i.e., random sampling of individuals) while the second assumption had to be presumed. Furthermore, ANOVA types of analyses assume normally distributed dependent variables. All variables used in the present analyses (i.e., COP-areas and reaction times) deviate from normality because they are positively skewed. For ANOVA and ANCOVA analyses it has been shown, however, that given equal sample sizes both procedures are rather insensitive to deviations from non-normality (Harwell, 2003; Harwell, Rubinstein, Hayes, & Olds, 1992). All analyses reported in this section are based on equal sample sizes. Therefore, dependent variables were not transformed in order to improve the interpretability of the results (i.e., results were reported in the terms of the original measurement metric). A second assumption in ANOVA analyses concerns the homogeneity of variances in between-subject comparisons or alternatively the sphericity assumption in within-subjects contrasts. Simulation studies have shown that power and α-level of the Type I error are only moderately influenced by unequal between-group variances (Harwell, 2003; Harwell et al., 1992). In line with meta-analytic analyses of Monte-Carlo simulations (Wilcox, 1987; cf. Keppel, 1991), Keppel (1991) argued that only a ratio between the greatest group variance and the smallest group variance of about nine to one should be considered problematic. Levene's tests of the equality of error variances were conducted to examine the validity of the variance homogeneity assumption. In cases where these tests were significant, between-group variance ratios were calculated to explore whether they were, indeed, within a problematic range. However, the ratio of between-subject standard deviations never exceeded the one to nine criterion across all the analyses.[10] Therefore, the Levene's tests of the equality of error variances were used as statistical tests of group differences in between-person variances rather than as mere assumption checks. The sphericity assumptions were tested statistically with Mauchly's test of sphericity. The significance of relevant comparisons was, however, evaluated with Pillai's trace multivariate tests. These tests are insensitive to deviations from sphericity and robust against inequality of variances on the between-subjects level (Olson, 1976). In addition to the statistical limitations of ANOVAs mentioned above, ANCOVAs are particularly sensitive to multicolinearity between the covariates in the model. Basing their argumentation on the inherent

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[10] All Levene's tests of equality of variance are presented in Appendix A. The highest ratio of between-person standard deviations across all analyses was 8.4. The average ratio of standard deviations was 4.08.

computational problems that arise if covariates in the model are highly correlated, Tabachnik and Fidell (2001) recommended that some of these covariates should be omitted in these cases. To circumvent this specific problem, ANCOVA analyses in this dissertation included only one covariate.

5.2 Age Differences in Processing Fluctuations in Postural Control

This section reports analyses that tested whether older adults' postural control fluctuates more than that of young adults and whether the postural control of males fluctuates more than that of females on three different time-scales (i.e., moment-to-moment, trial-to-trial, and day-to-day). Each of the two age groups contained 18 individuals with equal numbers of males and females.

Thus far, researchers of postural control performance have conventionally assessed moment-to-moment fluctuations on a single day to index a general level of postural control. This measure of postural control performance is more easily assessed than measures of trial-to-trial and day-to-day processing fluctuations. Therefore, it was examined whether potential group differences in the latter two time-scales were still statistically significant after controlling for interindividual differences in moment-to-moment processing fluctuations in postural control performance. This question was addressed statistically by ANCOVAs that included interindividual differences in moment-to-moment fluctuations as a covariate in the analyses of group differences in trial-to-trial and day-to-day processing fluctuations.

Postural control performance was assessed in simple standing and dual-task standing. Direct contrasts between postural control performance in simple standing and dual-task standing (e.g., age differences in dual-task costs) were, however, not the focus of this dissertation thesis. Therefore, group differences in processing fluctuations in postural control were examined separately for simple standing and dual-tasking postural control conditions. These two conditions can be used as two variants of interindividual differences in postural control. In the context of this dissertation thesis, separate analyses of processing fluctuations in both experimental conditions were used as replication analyses to demonstrate that the obtained findings hold under varying postural control conditions.

5.2.1 Significant Age Differences in Moment-to-Moment Processing Fluctuations

The level of moment-to-moment processing fluctuations was indexed by two different measures that referred to postural control performance in two different parts of the study design. The level of baseline moment-to-moment fluctuations was evaluated because it is equivalent to the measurements obtained in the commonly reported single-occasion postural control studies. The overall level of processing fluctuations across the daily assessment period indicated the average postural control performance on the shortest time-scale. The average performance across days is, however, influenced by learning and more reliable than the assessment on single days commonly used in the literature. Age differences in postural control performance at baseline as well as the average performance across the 45 days were examined in a two-by-two repeated measurement ANOVA, using age group (young vs. older) as a between-subjects factor and postural control measure (baseline vs. average daily) as a within-subjects factor. The sphericity assumption was met in the analyses. Figure 9 displays the means and standard errors of the moment-to-moment processing fluctuations of the two age groups at the two time points separately for both conditions.

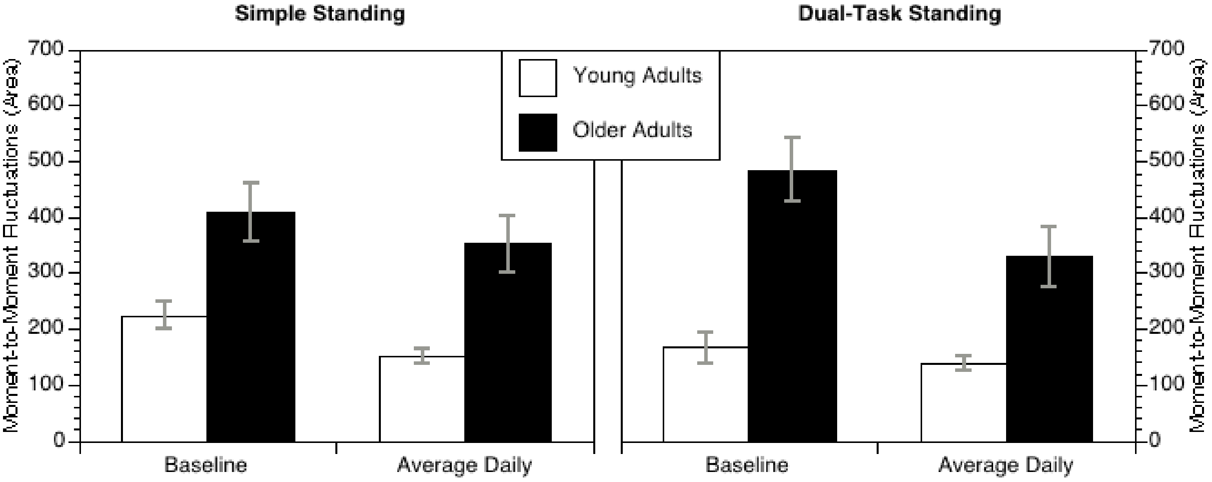

Figure 9. *Age Differences in Moment-to-Moment Processing Fluctuations in Postural Control at Baseline and on Average across 45 Days of Assessment in Simple Standing and Dual-Task Standing (Area/mm^2).*

The repeated measurement ANOVA analysis of the simple standing condition revealed a significant effect of age group, $F(1,36) = 13.24, p < .05, \eta_p^2 = .28$, and a significant effect of time point, $F(1,34) = 22.24, p < .05, \eta_p^2 = .40$. The interaction of age group and time point was not significant, $F(1,34) = 0.21, p > .10, \eta_p^2 = .01$. The sphericity assumption was met.

An ANOVA analysis of moment-to-moment processing fluctuations in dual-task standing found a significant effect of age group, $F(1,34) = 24.42, p < .05, \eta_p^2 = .42$), a significant effect of postural control measure, $F(1,34) = 22.51, p < .05, \eta_p^2 = .40$, and a significant interaction of age group and postural control measure, $F(1,34) = 10.91, p < .05, \eta_p^2 = .24$.

The analyses reported above demonstrated that older adults also displayed on average more moment-to-moment processing fluctuations in both experimental conditions than their younger counterparts. Furthermore, both age groups fluctuated more at baseline assessment than on average across the daily assessment period in both conditions. This finding indicated a learning effect in postural control performance in both age groups. The age group by postural control measure interaction in the dual-tasking condition was significant, caused by a stronger reduction of moment-to-moment processing fluctuations in the older adults than in the young adults. This effect primarily reflects that, relative to the older adults, the younger adults did not sway very much at baseline assessment.

5.2.2 Trial-to-Trial Processing Fluctuations in Postural Control

The level of trial-to-trial processing fluctuations is inversely related to the individual's capacity to consistently achieve good performances across repeated trials. In this context, they were indexed by the standard deviations across the five trials within a day, which were then averaged across the daily assessment period of 45 days. Group differences in trial-to-trial processing fluctuations were examined separately for simple standing and dual-task standing conditions. After analysis of simple age effects, it was examined whether age group explained between-person differences in trial-to-trial fluctuations over and above interindividual differences in moment-to-moment fluctuations. These analyses examined the hypothesis that age differences in trial-to-trial fluctuations contain information that is not captured by interindividual differences in fluctuations on the shorter moment-to-moment time scale.

5.2.2.1 Significant Age Differences in Trial-to-Trial Processing Fluctuations

Age differences in trial-to-trial processing fluctuations were examined separately for simple standing and dual-task standing conditions with Univariate ANOVAs with age group as a two-level between-subjects factor. Figure 10 displays means and standard errors of both conditions and both age groups.

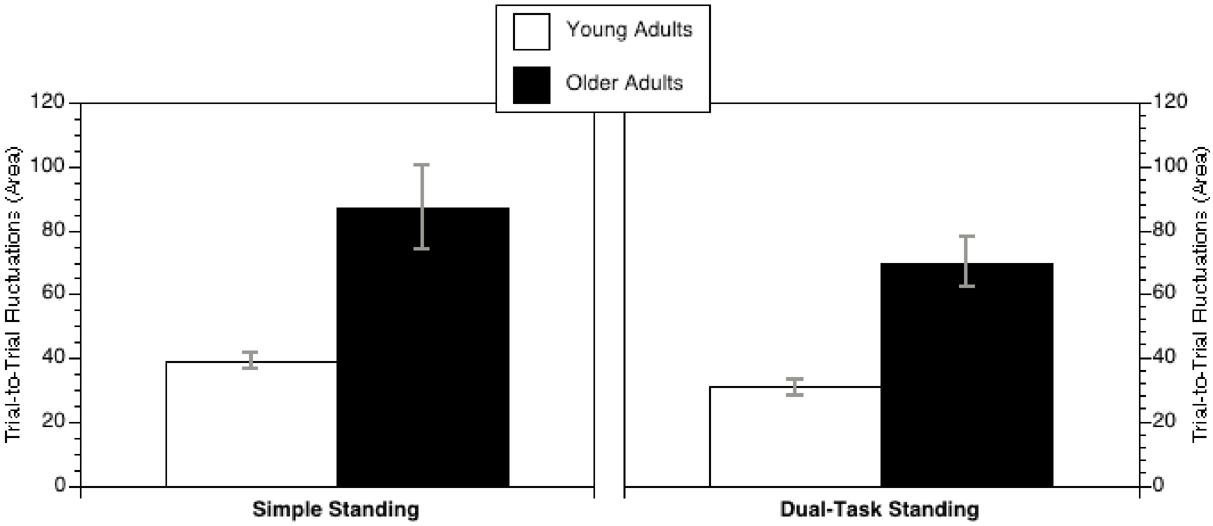

Figure 10. *Age Differences in Trial-to-Trial Processing Fluctuations in Postural Control on Average across 45 Days of Assessment in Simple standing and Dual-Task Standing (Area/mm^2).*

Univariate ANOVAs revealed a significant effect of age in simple standing, $F(1,34) = 13.25$, $p < .05$, $\eta_p^2 = .28$, and in dual-task standing, $F(1,34) = 22.44$, $p < .05$, $\eta_p^2 = .40$. Older adults fluctuated more from trial to trial than young adults in both conditions.

5.2.2.2 No Age Effects in Trial-to-Trial Fluctuations after Controlling for Interindividual Differences in Moment-to-Moment Fluctuations

The following analyses examined whether age differences in trial-to-trial processing fluctuations are completely predictable by interindividual differences in moment-to-moment fluctuations. Moment-to-moment processing fluctuations at baseline and average moment-to-moment fluctuations across the 45 days of assessment were introduced as covariates in the analyses of variance of trial-to-trial fluctuations. In the general linear model, the variance in the dependent variable that is associated with the effect of a given group factor is tested after the effects of covariates are partialed out. In this example, the ANCOVA analyses tested whether age group predicted variance in trial-to-trial fluctuations over and above interindividual differences in moment-to-moment fluctuations. Age differences in trial-to-trial fluctuations in both experimental conditions were examined separately.

The analyses were first run with baseline moment-to-moment processing fluctuations as a covariate. In a second analysis, the average moment-to-moment fluctuations across the 45 assessment days were introduced as a covariate. Figure 11 compares the overall amount of trial-to-trial fluctuations (labeled as Raw in the figure) to the residual fluctuations after controlling for moment-to-moment fluctuations at baseline and after controlling for average daily moment-to-moment fluctuations.[11]

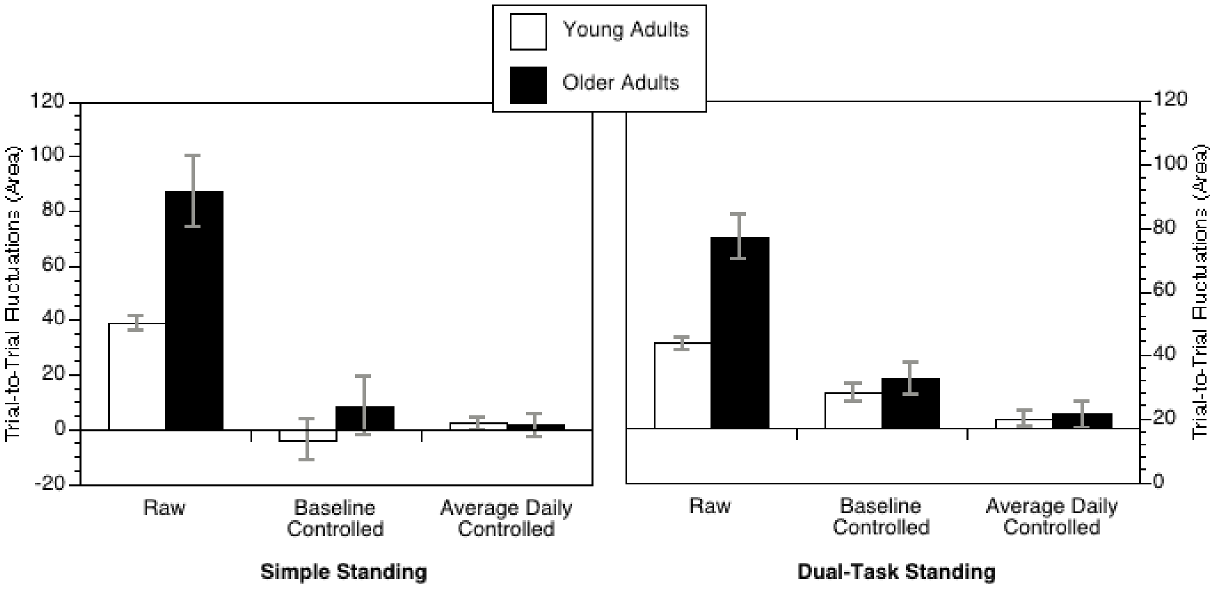

Figure 11. *Age Differences in Trial-to-Trial Processing Fluctuations in Simple standing and Dual-Task Standing Displayed as a Function of No-Control (i.e., Raw), Control for Moment-to-Moment Fluctuations at Baseline (i.e., Baseline Controlled), Control for Daily Average Moment-to-Moment Fluctuations.*

In simple standing, moment-to-moment fluctuations assessed at baseline were significantly related to the average trial-to-trial fluctuations, $F(1,33) = 70.95$, $p < .05$, $\eta_p^2 = .68$. The age effect was not significant after controlling for the effect of the covariate, $F(1,33) = 2.01$, $p > .10$, $\eta_p^2 = .06$. Interindividual differences in daily average moment-to-moment fluctuations were also significantly related to trial-to-trial fluctuations, $F(1,33) = 630.04$, $p < .05$, $\eta_p^2 = .95$. This control rendered the age effect non-significant, $F(1,33) = 0.03$, $p > .10$, $\eta_p^2 = .00$.

In dual-task standing, baseline moment-to-moment fluctuations were significantly related to trial-to-trial fluctuations, $F(1,33) = 106.98$, $p < .05$, $\eta_p^2 = .76$; the unique variance explained by age was not significant in this analysis, $F(1,33) = .92$, $p >.10$, $\eta_p^2 = .03$. Controlling for daily average moment-to-moment fluctuations showed a significant relationship between moment-to-moment fluctuations and trial-to-trial fluctuations, $F(1,33) = 209.74$, $p < .05$, $\eta_p^2 = .86$, and a non-significant unique effect of age, $F(1,33) = 0.16$, $p > .10$, $\eta_p^2 = .01$.

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[11] In the analyses of covariance reported above, the general linear model estimates three parameters: an intercept, a regression coefficient of the effect of the covariate (i.e., interindividual differences in moment-to-moment fluctuations), and a regression coefficient of the between-subject factor (i.e., age group). To obtain the average residual trial-to-trial fluctuations, the equations from the ANCOVA analyses were used. The average magnitude of residual fluctuations after controlling for interindividual differences in moment-to-moment fluctuations was given by the intercept plus the regression coefficient of the between-subject age group factor.

In sum, age differences in trial-to-trial processing fluctuations in postural control in both experimental conditions were statistically no longer significant after controlling for interindividual differences in moment-to-moment processing fluctuations. In this regard, it should be noted that control of moment-to-moment processing assessed at baseline was sufficient to explain age differences in trial-to-trial fluctuations. The negative amount of trial-to-trial fluctuations in the young adults group after controlling for baseline moment-to-moment processing fluctuations was statistically negligible.

5.2.3 Day-to-Day Processing Fluctuations in Postural Control

Day-to-day processing fluctuations index the individual's ability to perform at a consistently high level despite possible disturbances in the postural control system that occur from one day to the next. To obtain a "pure" estimate of day-to-day processing fluctuations, it was necessary to separate them from trends in the data possibly related to learning or drops in motivation. As mentioned in the Method section, trends in postural control could not be accurately described by a single parametrically meaningful learning function. It was thus decided to regress polynomial trends of increasing order to the full sample data in a multi-level fashion to estimate the optimal degree of control of trends. After the multi-level model identified the order of within-person, trends that sufficiently described the sample as a whole, polynomial regressions were conducted individually for each participant. The absolute deviations from each individual's specific curve indexed the participant's processing fluctuations from day to day. The level of day-to-day processing fluctuations was estimated by averaging the absolute within-person deviations across the days of assessment. In the following, these levels were examined with regard to possible age differences.

5.2.3.1 Outline of the Estimation Procedure of Trends in Postural Control

Trends in the postural control data across the 45 days were estimated with separate multi-level models for simple standing and dual-task standing. Time was defined as the order of occasions in which a participant was assessed. For example, if a particular participant was sick on the sixth day of the regular assessment in a given daily assessment period, the seventh day of assessment was his or her sixth possibility to learn and therefore coded as six. To enhance the interpretability of the results, the time variable was centered at the individual's means and divided by 45. Centering data in this way ensured that the intercept parameter in the analyses represented the average postural control performance across the whole 45-day assessment period. In dividing by 45, each fixed trend parameter represented the effect across the 45-day period. Parameters were tested for significance by means of χ^2-tests that were based on model comparisons with one degree of freedom. Polynomials of increasing order were fitted to the first level of analysis (i.e., the within-person level) to estimate the within-person trends. Model parameters that were associated with a given polynomial were always examined in the following order: The fixed effect was tested first, followed by a test of its random effect. If the random effect was significant, a statistical evaluation of its covariance parameters was conducted subsequently. The purpose of the multi-level modeling was to achieve the most parsimonious representation of the trends in the daily postural control data. Parameters that were not statistically significant were omitted from the analyses in subsequent models. This approach is recommended by Singer and Willet (2003) to avoid hitting boundary conditions (e.g., negative random variances). In a final step, age (Age) was introduced as an interaction term to evaluate whether age groups differed in their average performances or in their trends. A detailed description of the analyses can be found in Appendix B. The next two sections report only the final trend models of postural control performance including age interactions.

5.2.3.2 Trends in Simple Standing Postural Control

The final trend model of simple standing contained a linear trend (Linear), a quadratic trend (Quadratic), interindividual variability around these trends and a covariance between linear and quadratic trends. Age group interacted only with the average performance. Age was introduced as a dummy-coded interaction term (i.e., young adults were coded with 0 and older adults with 1) when specifying the three fixed effects in the final multilevel trend model of postural control performance in simple standing. The final results and the final parameter values of the series of multi-level analyses can be found in Table 5.

The final model was arrived at by performing the following equations:

First Level: $Y_{ij} = \pi_{0i} + \pi_{1i}(\text{Linear})\ \pi_{2i}(\text{Quadratic}) + \varepsilon_{ij}$

Second Level: $\pi_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \zeta_{0i}$

$\pi_{1i} = \gamma_{10} + \gamma_{11}(\text{Age}) + \zeta_{1i}$

$\pi_{2i} = \gamma_{20} + \gamma_{21}(\text{Age}) + \zeta_{2i}$

Where $\varepsilon_{ij} \sim N(0, \sigma_\varepsilon^2)$ and $\begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \end{bmatrix} \times \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \end{bmatrix}^t \approx N \begin{bmatrix} \sigma_0^2 & 0 & 0 \\ 0 & \sigma_1^2 & \sigma_{12} \\ 0 & \sigma_{21} & \sigma_2^2 \end{bmatrix}$

Table 5. *Multi-Level Modeling of Trends in Simple Standing Postural Control: Final Model Parameter Values.*

		Parameter	**Value**	**Model Change**
Fixed Effects				
Average	Intercept	γ_{00}	145.82	
	Age	γ_{01}	200.51	$\chi^2(1) = 12; p < .05$
Linear	Intercept	γ_{10}	-54.72	$\chi^2(1) = 104; p < .05$
	Age	γ_{11}		$\chi^2(1) = 0.2; p > .10$
Quadratic	Intercept	γ_{20}	65.42	$\chi^2(1) = 10.8; p < .05$
	Age	γ_{21}		$\chi^2(1) = 0.1; p > .10$
Random Effects (Variance Components)				
Level 1	Within-Person	σ_ε^2	3017.02	
Level 2	In Average	σ_0^2	25215	
	In Linear	σ_1^2	3644.43	$\chi^2(1) = 79.6; p < .05$
	In Quadratic Trend	σ_2^2	32318	$\chi^2(1) = 45.6; p < .05$
	In Linear by Quadratic	σ_{21}	-6246.35	$\chi^2(1) = 7.7; p < .05$

As can be seen in Table 5, moment-to-moment processing fluctuations in simple standing postural control decreased on average by 54.72 mm^2 across the 45 days of assessments. The significant quadratic term shows that learning gains were, on average, more pronounced at the beginning of the assessment and leveled off towards the end. Significant interindividual differences (i.e., significant second level random variances) were found in the linear slope parameter as well as in the quadratic curvature parameter. The strengths of the linear slope and the quadratic trend covaried negatively. Participants with a stronger linear learning slope demonstrated less curvature and vice versa. Multilevel model comparisons revealed, however, that the shape of the trends in simple standing postural control did not differ systematically between age groups. Significant age differences were only found in the average postural control performance (as shown in the significant effect of age on the average). Figure 12 displays trends in simple standing postural control separately for both age groups.

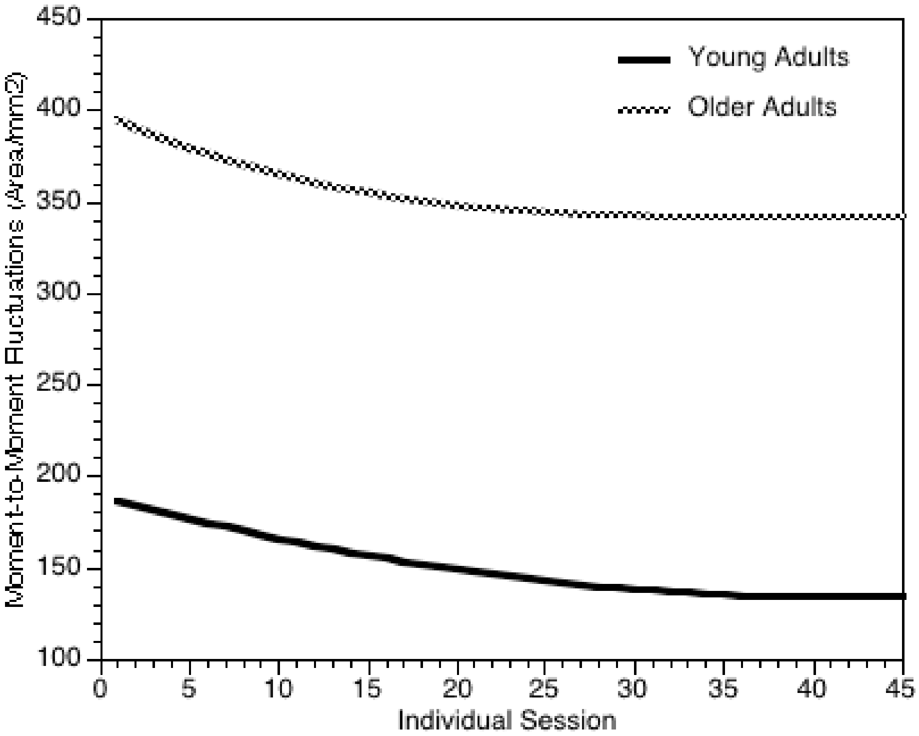

Figure 12. *Average Trends in Simple Standing as a Function of Age.*

5.2.3.3 Trends in Dual-Task Standing Postural Control

Multilevel models examining trends in dual-task standing revealed that trends in dual-tasking postural control were best described with a linear trend (Linear), a quadratic trend (Quadratic), and a cubic trend (Cubic). Significant fixed and random effects were estimated for the linear and quadratic trends. However, only the random effect of the cubic trend was significant. Interindividual differences in the linear trend in dual-task standing covaried negatively with interindividual differences in average performance, with interindividual differences in the strength of the quadratic trend and with interindividual differences in the cubic trend. Age was implemented as a binary, dummy-coded interaction term. Table 6 displays the results of the multi-level analyses.

The final model was arrived at using the following equations:

First Level: $Y_{ij} = \pi_{0i} + \pi_{1i}(\text{Linear}) + \pi_{2i}(\text{Quadratic}) + \pi_{3i}(\text{Cubic}) + \varepsilon_{ij}$

Second Level: $\pi_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \zeta_{0i}$

$\pi_{1i} = \gamma_{10} + \gamma_{11}(\text{Age}) + \zeta_{1i}$

$\pi_{2i} = \gamma_{20} + \gamma_{21}(\text{Age}) + \zeta_{2i}$

$\pi_{3i} = \gamma_{30} + \gamma_{31}(\text{Age}) + \zeta_{3i}$

$$\text{Where} \quad \varepsilon_{ij} \sim N(0, \sigma_\varepsilon^2) \text{ and} \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix} \times \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix}^t \approx N \begin{bmatrix} \sigma_0^2 & \sigma_{01} & 0 & 0 \\ \sigma_{10} & \sigma_1^2 & \sigma_{12} & \sigma_{13} \\ 0 & \sigma_{21} & \sigma_2^2 & 0 \\ 0 & \sigma_{31} & 0 & \sigma_3^2 \end{bmatrix}$$

Table 6. *Multi-Level Modeling of Trends in Dual-Task Standing Postural Control: Final Model Parameter Values.*

		Parameter	Value	Model Change
Fixed Effects				
Average	Intercept	γ_{00}	130.18	
	Age	γ_{01}	158.16	$\chi^2(1) = 15.7; p < .05$
Linear	Intercept	γ_{10}	-34.53	$\chi^2(1) = 126.8; p < .05$
	Age	γ_{11}		$\chi^2(1) = 2.4; p > .10$
Quadratic	Intercept	γ_{20}	23.25	$\chi^2(1) = 43.0; p < .05$
	Age	γ_{21}	144.96	$\chi^2(1) = 3.8; p = .05$
Cubic	Intercept	γ_{30}	91.16	$\chi^2(1) = 2.4; p >.10$
	Age	γ_{31}	-290.65	$\chi^2(1) = 7.4; p < .05$
Random Effects (Variance Components)				
Level 1	Within-Person	σ_ε^2	1619.3	
	In Average	σ_0^2	10861	
	In Linear	σ_1^2	4403.45	$\chi^2(1) = 145.2; p < .05$
	In Quadratic	σ_2^2	15251	$\chi^2(1) = 59.0; p < .05$
Level 2	In Cubic	σ_3^2	99713	$\chi^2(1) = 5.6; p < .05$
	In Average by Linear	σ_{10}	-1039.34	$\chi^2(1) = 8.5; p < .05$
	In Linear by Quadratic	σ_{21}	-3292.68	$\chi^2(1) = 8.6; p < .05$
	In Linear by Cubic	σ_{31}	-13485	$\chi^2(1) = 4.8; p < .05$

Table 6 shows that moment-to-moment processing fluctuations in dual-task standing postural control decreased on average by 34.33 mm^2 across the daily assessment period. Learning gains were, on average, more pronounced at the beginning than at the end of the assessment as indicated by the significant quadratic trend. Significant interindividual differences were found in the linear slope parameter as well as in the curvature parameter. The significant random variance in the cubic trend parameter indicates that some participants showed more than one phase of increase or decrease of performance across the whole assessment period. The significant covariance parameters of the linear slope indicated that participants with better average performance showed less learning and that better learning during the early measurement occasions was associated with lower quadratic and cubic trends. Furthermore, age significantly affected the average performance, the quadratic trend and the cubic trend in dual-task standing postural control. The interpretation of these age interactions in trends is difficult if it is based only on numerical values. Figure 13 displays the average curves in dual-task standing across the daily assessment period for young and older adults.

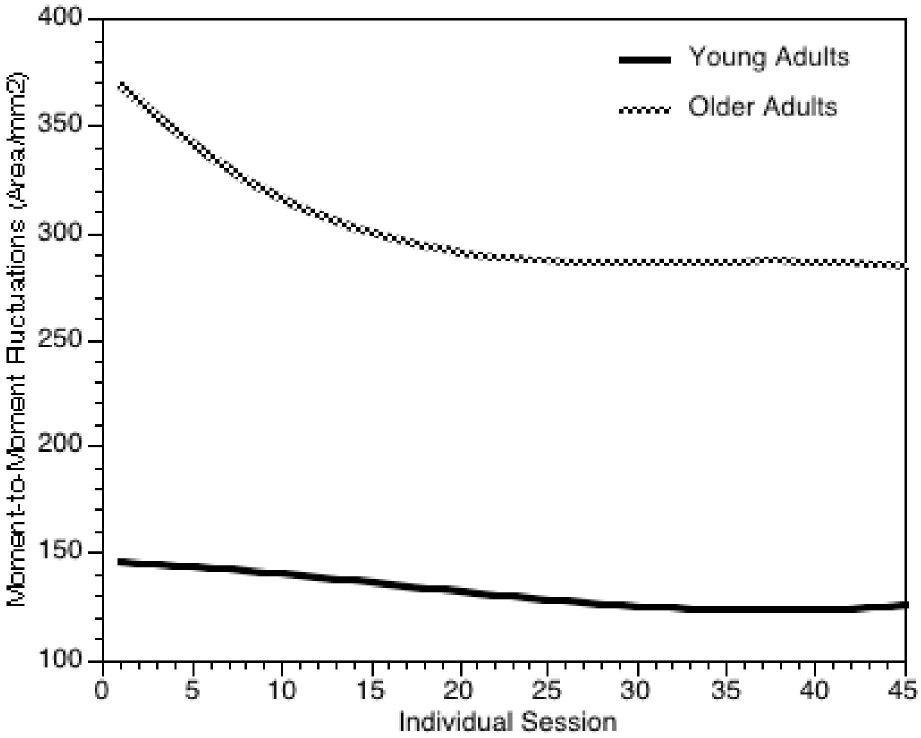

Figure 13. *Average Trends in Dual-Task Standing as a Function of Age.*

As depicted in the figure, the significant age interactions in the quadratic and cubic trends resulted from a stronger decrease of moment-to-moment fluctuations in older adults than in younger adults primarily at the beginning of the testing period and an increase in moment-to-moment fluctuations in the last week of assessment that was only observed in the young adult group.

5.2.3.4 Age Differences in Day-to-Day Processing Fluctuations

The individuals' level of day-to-day processing fluctuations was estimated in the following manner: Within persons linear and quadratic functions of time were regressed on the individual's time series in simple standing while linear, quadratic, and cubic functions of time were regressed on the individual's time series in dual-task standing (i.e., using the final models described in the previous sections). The absolute residuals from these within-person regressions were the averaged. Age differences in day-to-day processing fluctuations were analyzed separately for both experimental conditions with two Univariate ANOVAs with age as a between-subject factor. Means and standard errors of day-to-day processing fluctuations in postural control are displayed in Figure 14 as a function of age and experimental condition.

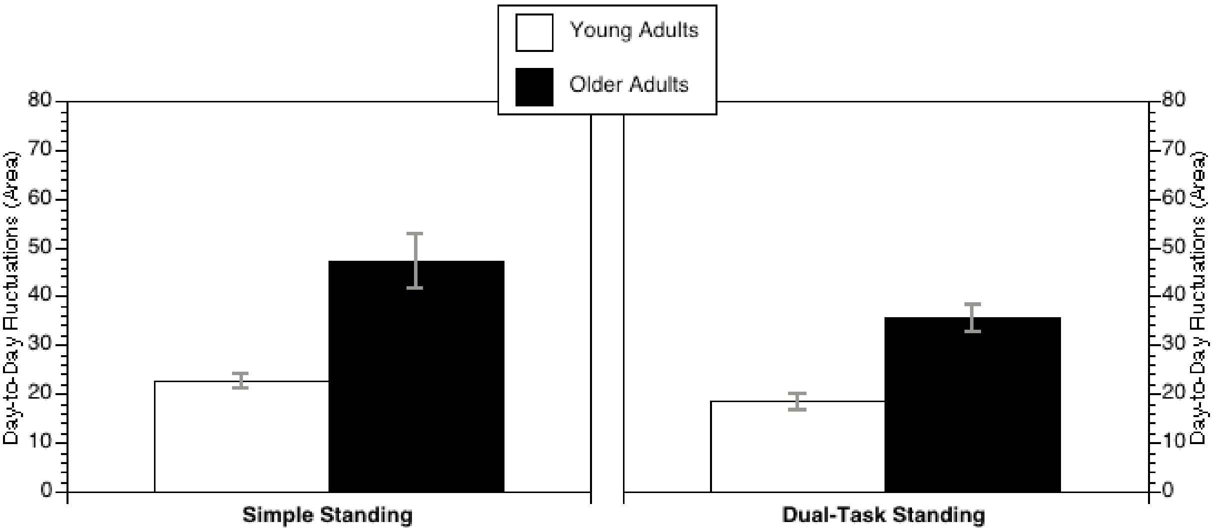

Figure 14. *Age Differences in Day-to-Day Processing Fluctuations in Postural Control on Average across 45 Days of Assessment in Simple Standing and Dual-Task Standing (Area/mm²)*

Age significantly affected day-to-day processing fluctuations in simple standing, $F(1,34) = 16.92, p < .05, \eta_p^2 = .33$, and in dual-task standing, $F(1,34) = 29.04, p < .05, \eta_p^2 = .46$. Day-to-day fluctuation in postural control was more pronounced in older adults than in young adults.

5.2.3.5 Significant Age Differences in Day-to-Day Fluctuations after Controlling for Moment-to-Moment Sway at Baseline but not after Controlling for Moment-to-Moment Sway across 45 Days

To evaluate whether age differences in day-to-day processing fluctuations could be predicted by interindividual differences in levels of moment-to-moment fluctuations, these differences were introduced as covariates in the analyses of day-to-day fluctuations. The analyses were first run with baseline moment-to-moment processing fluctuations as covariate in order to evaluate if a single occasion measurement of postural control performance accounts for a fair amount of age differences in day-to-day processing fluctuations. Subsequently, average moment-to-moment fluctuations across the 45 days of assessment were introduced as a covariate to test whether age differences in day-to-day fluctuations are potentially a functional consequence of processing fluctuations at the shortest time-scale. All analyses were run separately for simple standing and dual-task standing conditions. In Figure 15, means and standard errors of the level of day-to-day fluctuations in postural control performance are displayed as a function of age group and experimental condition. The illustration contains level of day-to-day fluctuations without control (labeled as Raw), the residual day-to-day fluctuation after the control of individual levels of baseline moment-to-moment fluctuations, and average moment-to-moment sway across the daily assessment period.

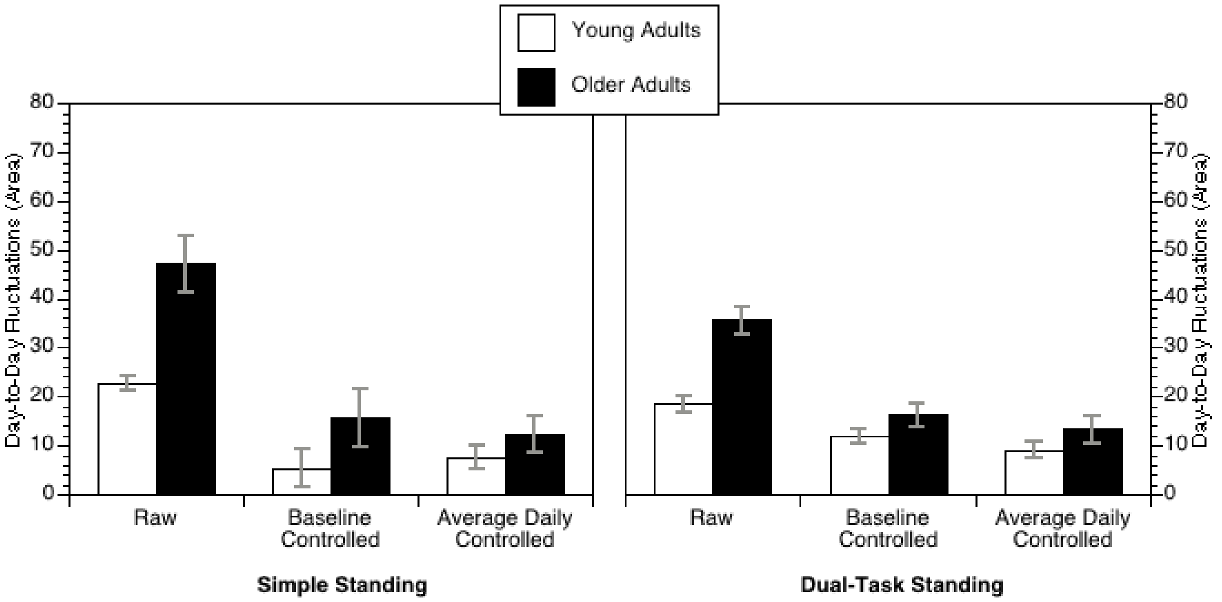

Figure 15. *Age Differences in Day-to-Day Processing Fluctuations in Simple standing and Dual-Task Standing Displayed as a Function of No-Control (i.e., Raw), Controlling for Moment-to-Moment Fluctuations at Baseline (i.e., Baseline Controlled), Controlling for Average Daily Moment-to-Moment Fluctuations (i.e., Average Daily Controlled).*

Interindividual differences in baseline moment-to-moment sway and average sway across the 45 days were significantly related to day-to-day fluctuations in simple standing, $F(1,33) = 39.51, p < .05, \eta_p^2 = .55$, $F(1,33) = 121.08, p < .05, \eta_p^2 = .79$. The effect of age on day-to-day fluctuations in simple standing remained significant after controlling for interindividual differences in baseline sway, $F(1,33) = 4.63, p < .05, \eta_p^2 = .12$, but not significant after controlling for interindividual differences in average moment-to-moment sway across the daily assessment period, $F(1,33) = 1.86, p > .10, \eta_p^2 = .05$.

Day-to-day fluctuations in dual-task standing were marginally significantly affected by age, $F(1,33) = 4.01, p = .054, \eta_p^2 = .11$, also after the control of the effect of baseline moment-to-moment fluctuations, $F(1,33) = 83.22, p < .05, \eta_p^2 = .72$. They were also marginally affected by age, $F(1,33) = 3.24$, $p = .081$, $\eta_p^2 = .09$, after controlling for the interindividual differences in average moment-to-moment fluctuations across the daily assessment period, $F(1,33) = 74.30$, $p < .05$, $\eta_p^2 = .69$.

In both experimental conditions, age differences in the amount of fluctuations in postural control performance between days were greater than could be expected by considering interindividual differences in moment-to-moment fluctuations assessed at a single occasion. The age differences were significantly reduced, however, if the average of moment-to-moment fluctuations over a long time period was used as a control variable.

5.3 An Individual-Based Control Strategy of Interindividual Differences in Moment-to-Moment Sway in the Analysis of Trial-to-Trial Fluctuations

In the analyses of age differences in trial-to-trial fluctuations as described in Section 5.2.2.2, controlling for interindividual differences in moment-to-moment processing fluctuations has some disadvantages. First of all, fluctuations on the shorter time scale are correlated with age. As a consequence, a control of these differences might have partialed out age-related variance on longer time scales simply because of a common moderator relationship. Second, this control procedure assumes variance equivalence between within-person variability and between-person variability and homogeneity of the relationship across persons.[12] Thus, the relationship between trial-to-trial and moment-to-moment processing fluctuations in postural control was, therefore, examined on the within-person level.

5.3.1 Interindividual Differences in Within-Person Relations of Moment-to-Moment and Trial-to-Trial Fluctuations

Every individual in the sample provided approximately 45 daily estimates of trial-to-trial fluctuations (i.e., the SD across trials within a day) and 45 daily moment-to-moment fluctuations (i.e., the mean across trials within a day). Therefore, it was possible to regress trial-to-trial fluctuations within days on the mean moment-to-moment fluctuations on the same days within persons. Figure 16 displays the standardized regression coefficients obtained from these analyses for age groups and experimental conditions separately. As can be seen in the diagram, there were

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[12] As has been laid out in section 4.5.4, it is a common assumption that increases in the central tendency of given variable also increase the likelihood of an increasing variability because of an associated increase in the distance to performance boundaries. The control of between-person differences nevertheless allows the examination of whether age-related interindividual differences in trial-to-trial performances can be predicted by the assessment of moment-to-moment fluctuations.

large interindividual differences in the within-person relationships between trial-to-trial and moment-to-moment processing fluctuations.

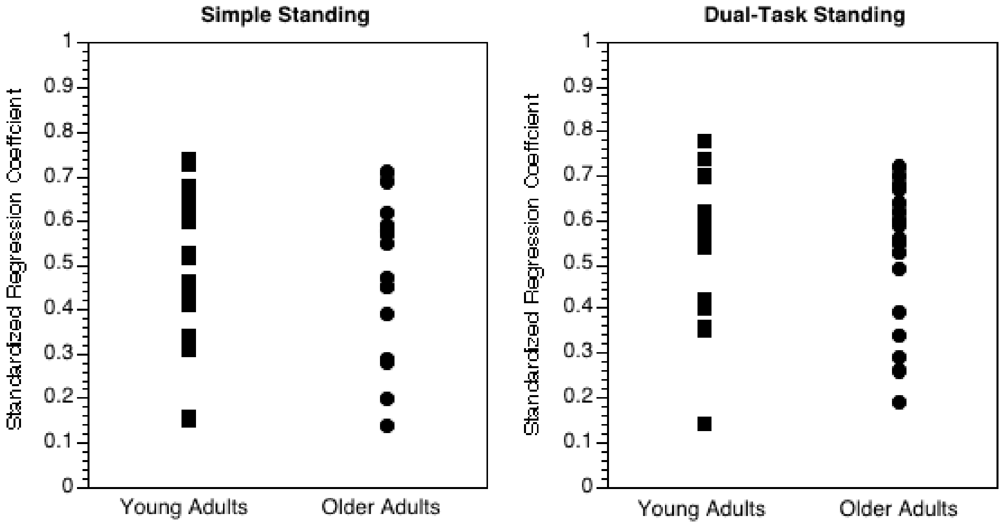

Figure 16. *Standardized Regression Coefficients of the Intraindividual Relationships between Moment-to-Moment and Trial-to-Trial Fluctuations Displayed Separately for Age Groups and Experimental Conditions.*

To test whether interindividual differences in the intraindividual relationships of trial-to-trial and moment-to-moment processing fluctuations were significant, two multi-level models for simple standing and dual-task standing conditions were employed. In both cases, intraindividual variability in trial-to-trial processing fluctuations was predicted with intraindividual variability in moment-to-moment fluctuations (Moment-to-Moment) at the first level of analysis. Moment-to-moment fluctuations were centered with respect to the persons' mean performance in order to eliminate between-person differences in this respect. Thus, an individual's moment-to-moment fluctuations were expressed as deviances from his or her own average. Furthermore, these deviances were scaled to 100 mm^2 per unit to allow an easier interpretation of the results. Interindividual differences in the average performances and in the strength of the first level relationships were examined at the second level. At this level, possible age differences were of particular interest and tested with a dummy variable (Age) that coded young adults as 0 and older adults as 1. Consequently, the intercept of the model denoted the average trial-to-trial fluctuations of young adults.

The final multilevel model was arrived at by the following equations:

First Level: $Y_{ij} = \pi_{0i} + \pi_{1i}(\text{Moment-to-Moment}) + \varepsilon_{ij}$

Second Level: $\pi_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \zeta_{0i}$

$\pi_{1i} = \gamma_{10} + \gamma_{11}(\text{Age}) + \zeta_{1i}$

where

$$\varepsilon_{ij} \sim N(0, \sigma_\varepsilon^2) \text{ and } \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \end{bmatrix} \approx N\begin{bmatrix} \sigma_0 \\ \sigma_1 \end{bmatrix}$$

For reasons mentioned in the Method section (Section 4.5.1), parameters were tested by model comparisons. Age group, γ_{01}(Age), was introduced first at the second level to account for age differences in the average trial-to-trial fluctuations. In a second step, moment-to-moment fluctuations were introduced at the first level. The fixed effect of the slope π_{1i}(Moment-to-Moment, i.e., average relationship) and random effect of the slopes γ_{10} (i.e., interindividual variance in the relationships) were examined one after the other. In a last step, a possible age interaction in the strengths of the slopes γ_{11}(Age) was tested. Table 7 displays the results of the multi-level analyses of trial-to-trial fluctuations in simple standing and dual-task standing.

Table 7. *Results of Fitting Multi-Level Models to Trial-to-Trial Fluctuations in Simple Standing and Dual-Task Standing: The Effect of Age*

Simple Standing

		Parameter	**Value**	**Model Change**
Fixed Effects				
Average Trial-to-Trial Fluctuations	Intercept	γ_{00}	38.53	
	Age	γ_{01}	48.38	$\chi^2(1) = 11.8; p < .05$
Relation to Moment-to-Moment Fluctuations	Intercept	γ_{10}	25.92	$\chi^2(1) = 260.5; p < .05$
	Age	γ_{11}	-.13	$\chi^2(1) = 0.0; p > .10$
Random Effects (Variance Components)				
Level 1	Within-Person	σ_ε^2	926.7	
Level 2	Average Trial-to-Trial Fluctuations	σ_0^2	1481.3	
	Relation to Moment-to-Moment Fluctuations	σ_1^2	86.5	$\chi^2(1) = 39.1; p < .05$

Dual-Task Standing

		Parameter	**Value**	**Model Change**
Fixed Effects				
Average Trial-to-Trial Fluctuations	Intercept	γ_{00}	30.73	
	Age	γ_{01}	39.32	$\chi^2(1) = 18.3; p < .05$
Relation to Moment-to-Moment Fluctuations	Intercept	γ_{10}	25.41	$\chi^2(1) = 469,6; p < .05$
	Age	γ_{11}	2.71	$\chi^2(1) = 0.4; p > .10$
Random Effects (Variance Components)				
Level 1	Within-Person	σ_ε^2	465.68	
Level 2	Average Trial-to-Trial Fluctuations	σ_0^2	575.54	
	Relation to Moment-to-Moment Fluctuations	σ_1^2	60.91	$\chi^2(1) = 24.2; p < .05$

As can be seen in Table 7, there was a significant effect of age on average trial-to-trial fluctuations. Older adults fluctuated on average 48.83 mm^2 more in simple standing and 39.32 mm^2 more in dual-task standing than young adults. On the within-person level, a significant relationship between moment-to-moment and trial-to-trial processing fluctuations was found in both conditions. On average, a deviance of 100 mm^2 from the individual's mean in moment-to-moment fluctuations was associated with an increase of trial-to-trial processing fluctuations of 25.92 mm^2 in simple standing and of 25.41 mm^2 in dual-task standing. The significant random parameters of these relations indicate that the relationship between processing fluctuations from moment-to-moment and between trials differed significantly in strength between persons in both conditions.

5.3.2 Significant Age Differences in Within-Person Residual Trial-to-Trial Fluctuations

The fact that the relationship between processing fluctuations in postural control on different time-scales might differ between individuals necessitates an individual-based control of this relationship. Thus, daily measures of moment-to-moment fluctuations were regressed on daily measures of trial-to-trial fluctuations for each individual. The averaged absolute deviations from the linear relationships between the two measures indexed the amount of intraindividual trial-to-trial fluctuations that were independent of processing fluctuations from one moment to the next. Figure 17 shows means and standard errors of trial-to-trial fluctuations that were controlled for the within-person relationship to moment-to-moment fluctuations for both age groups and experimental conditions and contrasts them to the uncontrolled fluctuations from trial to trial.

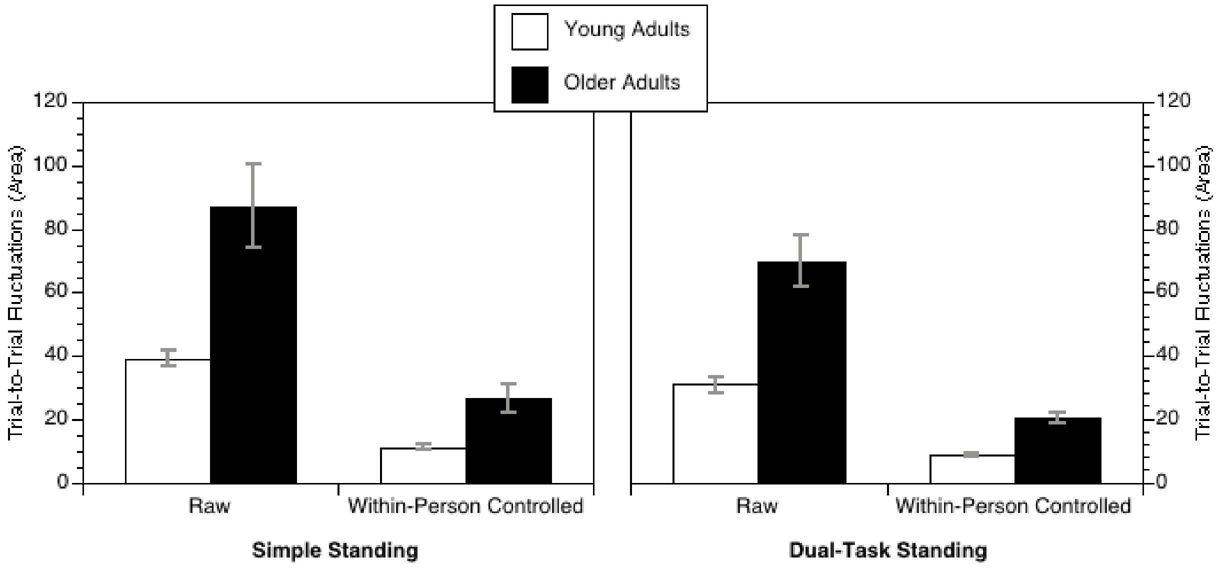

Figure 17. *Age Differences in Trial-to-Trial Processing Fluctuations in Simple Standing and Dual-Task Standing Displayed as a Function of No-Control (i.e., Raw) and Person Centered Control of Moment-to-Moment Fluctuations across Days (i.e., Within-Person Controlled).*

Two univariate ANOVAs revealed main effects of age on trial-to-trial processing fluctuations in postural control that were controlled for intraindividual variability in moment-to-moment fluctuations: simple standing, $F(1,34) = 12.87$, $p < .05$, $\eta_p^2 = .28$; dual-task standing, $F(1,34) = 32.96$, $p < .05$, $\eta_p^2 = .49$. Trial-to-trial processing fluctuations were stronger in older adults than in young adults after controlling for the influence of processing fluctuations on a shorter time scale.

5.4 Sex Differences in Processing Fluctuations in Postural Control

This section reports analyses regarding potential sex differences in processing fluctuations in postural control. More specifically, the analyses addressed two related questions. It was investigated whether women demonstrate a more stable postural control performance from moment to moment, from trial to trial, and between days than men and whether this potential female benefit interacted with age. Thus, sex was introduced in addition to age group as a between-person factor in the analyses of processing fluctuations on the three time scales.

5.4.1 Sex Differences in Moment-to-Moment Processing Fluctuations

Age and sex differences in postural control performance were examined with a 2 x 2 x 2 repeated measurement ANOVA. Age group (young vs. old) and sex (female vs. male) constituted between-subjects factors. Postural control measure (baseline moment-to-moment fluctuations vs. average daily moment-to-moment fluctuations) was tested as a within-subjects factor. Figure 18 displays the means and standard errors of the moment-to-moment processing fluctuations of the two age and sex groups at the two time points separately for both conditions.

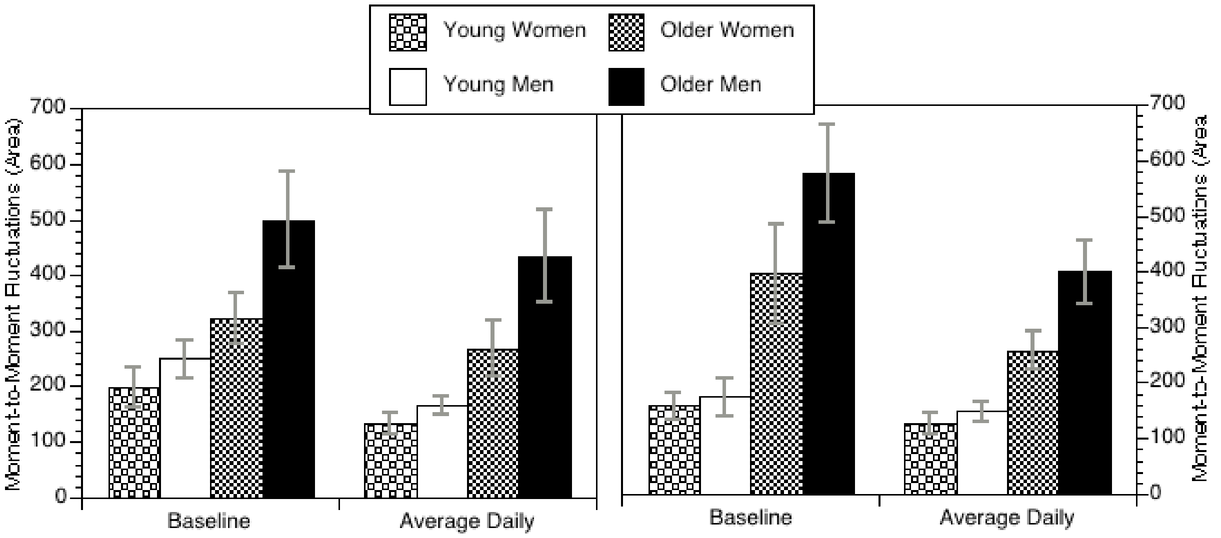

Figure 18. *Age and Sex Differences in Moment-to-Moment Processing Fluctuations in Postural Control at Baseline and on Average across 45 Days of Assessment in Simple Standing and Dual-Task Standing (Area/mm²).*

ANOVA analysis of moment-to-moment fluctuations in simple standing postural control found a significant main effects of age, $F(1,32) = 14.09, p < .05, \eta_p^2 = .32$, of sex, $F(1,32) = 4.57, p < .05, \eta_p^2 = .13$, and of postural control measure, $F(1,32) = 21.09, p < .05, \eta_p^2 = .40$. No two-way or three-way interaction between the three factors was significant (i.e., all p-values were greater than .10). The picture was slightly different for dual-task standing than for simple standing. In dual-task standing the main effects of age, $F(1,32) = 26{,}91$, $p < .05$, $\eta_p^2 = .46$, and time point, $F(1,32) = 21.27$, $p < .05$, $\eta_p^2 = .40$, were significant, but the main effect of sex was only marginally significant, $F(1,32) = 3.37$, $p = .08$, $\eta_p^2 = .10$. Furthermore, the two-way interaction of age by time point was significant, $F(1,32) = 10.42$, $p < .05$, $\eta_p^2 = .25$. No other two-way or three-way interaction of the three factors was significant (i.e., all p-values were greater than .10).

In summary, women fluctuated significantly less in simple standing and marginally less in dual-task standing than men. This effect, however, did not interact with age group or postural control. Regardless of sex, older adults fluctuated more than young adults in both experimental conditions. Young and older adults of both sexes displayed a comparable reduction of moment-to-moment fluctuations in simple standing if baseline performance and average performances across the daily assessment period were contrasted. Older adults, regardless of sex, showed a more pronounced reduction in fluctuations than young adults in dual-task standing.

5.4.2 No Reliable Sex Differences in Trial-to-Trial Processing Fluctuations

Group differences in trial-to-trial processing fluctuations were examined separately for both conditions with two Univariate two-by-two ANOVAs, in which age group and sex were introduced as between-subject factors. Group differences in means and their respective standard errors are plotted separately for both experimental conditions in Figure 19.

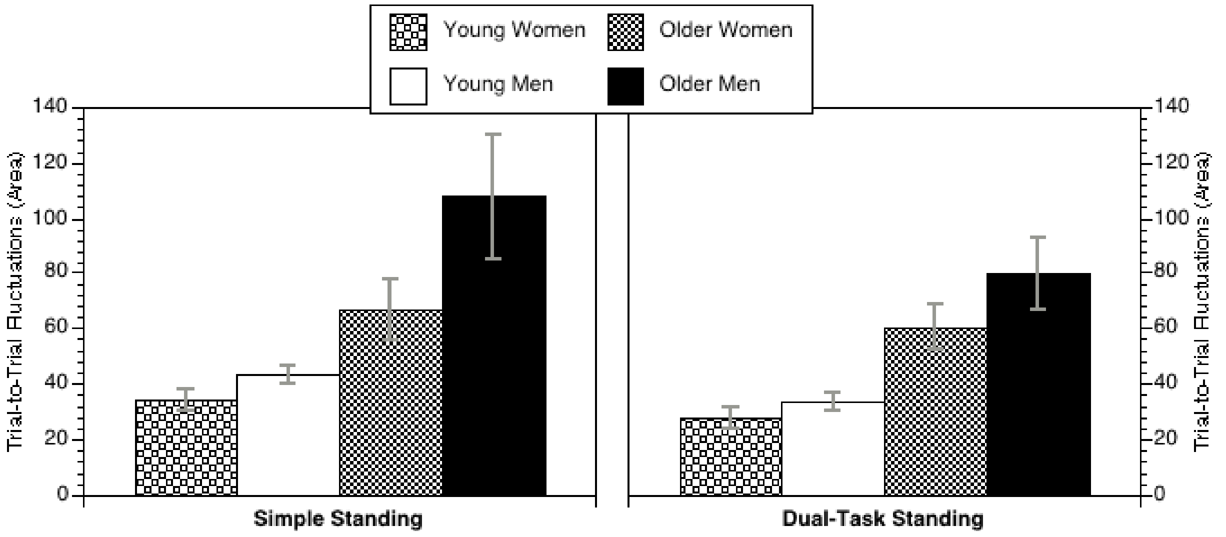

Figure 19. *Age and Sex Differences in Trial-to-Trial Processing Fluctuations in Postural Control (Area/mm²) in Simple Standing and Dual-Task Standing.*

Univariate analyses revealed significant main effects of age in simple standing, $F(1,32) = 14.67$, $p < .05$, $\eta_p^2 = .31$, and dual-task standing, $F(1,32) = 23.13$, $p < .05$, $\eta_p^2 = .42$. The main effect of sex was marginally significant in simple standing, $F(1,32) = 4.03, p = .05, \eta_p^2 = .11$, and not significant in dual-task standing, $F(1,32) = 2.30, p > .10, \eta_p^2 = .07$. The interactions in both conditions between age group and sex were not significant (i.e., p-values greater than .10).

The amount of trial-to-trial processing fluctuations differed only marginally between the two sexes and only in the simple standing condition. Older adults fluctuated more than young adults from one trial to the next regardless of sex.

5.4.3. No Reliable Sex Differences in Day-to-Day Processing Fluctuations

Two Univariate two-by-two ANOVAs in which age group and sex were introduced as between-subject factors were conducted to examine potential sex differences in day-to-day processing fluctuations in simple standing and dual-task standing postural control performances. Means and their respective standard errors are plotted separately for both experimental conditions in Figure 20 as a function of age and sex.

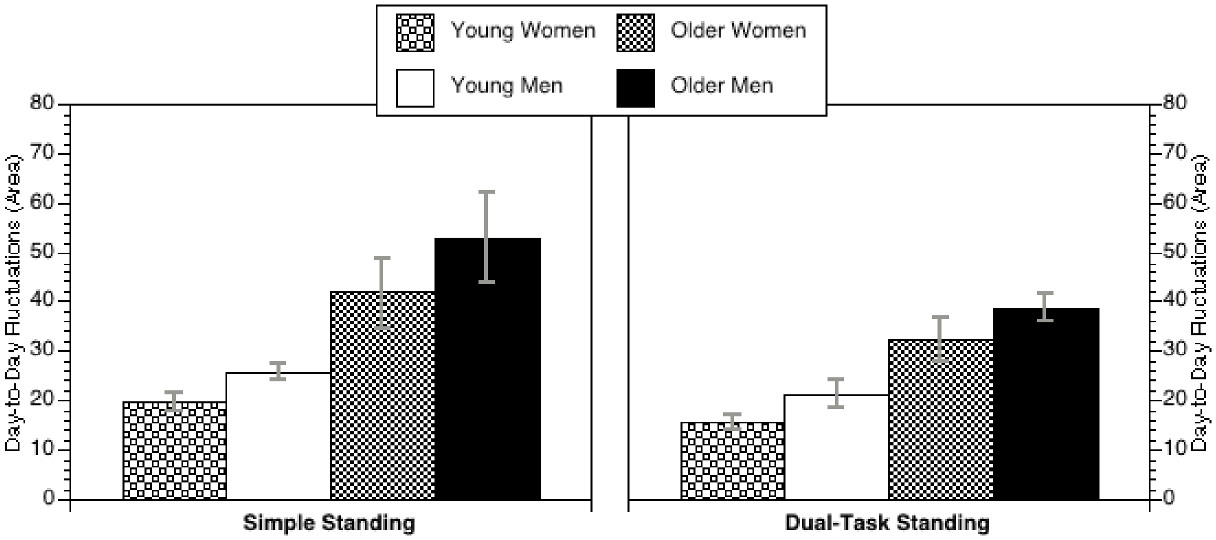

Figure 20. *Age and Sex Differences in Day-to-Day Processing Fluctuations in Postural Control (Area/mm²) in Simple Standing and Dual-Task Standing.*

Univariate analyses found significant main effects of age on day-to-day fluctuations in simple standing, $F(1,32) = 17.05, p < .05, \eta_p^2 = .35$, and dual-task standing, $F(1,32) = 30.56, p < .05, \eta_p^2 = .49$. The main effect of sex was not significant in day-to-day fluctuations in simple standing, $F(1,32) = 2.10, p > .10, \eta_p^2 = .06$, and marginally significant in day-to-day fluctuations in dual-task standing, $F(1,32) = 2.30, p = .064, \eta_p^2 = .11$. The interaction between age group and sex with respect to the level of day-to-day processing fluctuations was neither significant in the simple standing condition, $F(1,32) = 0.16, p > .10, \eta_p^2 = .01$, nor was it significant in the dual-task standing condition, $F(1,32) = 0.02, p > .10, \eta_p^2 = .00$.

The level of day-to-day processing fluctuations differed only marginally between the two sexes and only in the dual-task standing condition. Regardless of sex, older adults fluctuated more in their postural control performances between days than young adults.

5.5 Processing Fluctuations in Postural Control: Cross-Domain Couplings

Mechanisms operating at the within-person level are the theoretical focus of this dissertation. Consequently, the main dependent variables in the analyses of coupling between postural control and cognition were conducted at the level of single individuals. Specifically, this section addresses the questions whether processing fluctuations in postural control can be predicted by processing fluctuations in spatial working memory at the level of the individual and whether interindividual differences in these relationships are associated with interindividual differences in other variables of interest.

Day-to-day processing fluctuations in reaction time performances in a spatial working memory task, which strongly demanded attentional control, were used as indicators of fluctuations in attentional control. Performances in working memory (WM) were assessed in a seated position independently of postural control performances. Day-to-day processing fluctuations in the reaction times in WM performances were indicated by the residual intraindividual variation around intraindividual exponential learning trends. Cross-domain analyses were further restricted to the investigation of day-to-day processing fluctuations in simple standing. Thus, it was assured that potential cross-domain interrelationships were not a consequence of the experimental design. Furthermore, in dual-task situations postural control performance and cognitive performance have to be considered conjointly as performance indicators. If individuals perform under conditions of cross-domain resource competition, processing fluctuations in spatial working memory could influence either the postural control performance or the cognitive performance that may confound the estimation of cross-domain couplings at the day-to-day level.

First, within-person correlation coefficients relating processing fluctuations in postural control and working memory are reported for descriptive purposes. Second, a number of multi-level analyses that examined the statistical significance of the observed relationships and potential group differences in these relationships are presented.

5.5.1 Within-Person Correlations of Processing Fluctuations in Postural Control and Working Memory

Figure 21 shows distributions of correlation coefficients that indicate the strength of the relation between processing fluctuations in postural control and working memory for each and every individual in the sample. The purpose of this illustration is to provide a visual representation of the interindividual differences in the main dependent variable, which are statistically examined with multi-level models. However, the illustration can only be viewed as an approximation because the within-person interrelationships that are modeled in the multi-level analyses do not correspond directly to the correlations estimated within single persons. In multi-level models, information about the sample characteristics is used in the estimation of the within-person relationships. Multi-level models assume, for example, a normal distribution of first-level coefficients across second level-units (i.e., persons) and weight first-level coefficients according to their number of observations (Raudenbush & Bryk, 2002).

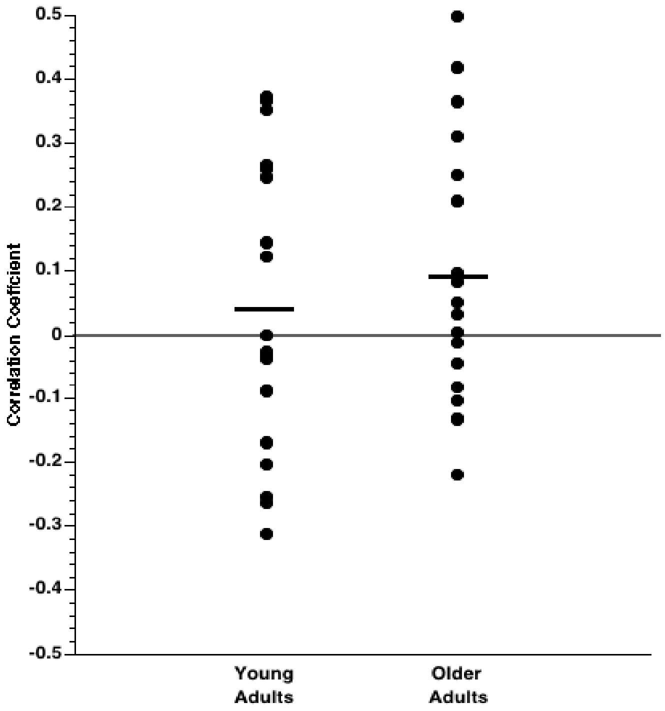

Figure 21. *Intraindividual Correlation Coefficients of Processing Fluctuations in Postural Control and Working Memory as a Function of Age.*
Note: Thick Black Lines Denote Average Coefficients of the Two Groups.

As can be seen in Figure 21, there were large interindividual differences in the strength of couplings between processing fluctuations across domains. There was also a subtle age difference in the average strength of the intraindividual couplings. Figure 22 displays the same coupling coefficients as a function of age and sex.

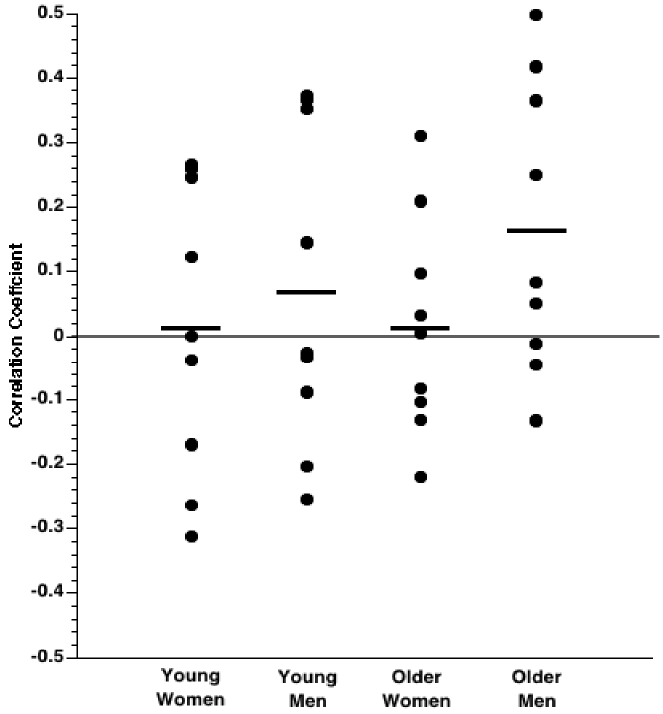

Figure 22. *Intraindividual Correlation Coefficients of Processing Fluctuations in Postural Control and Working Memory as a Function of Age and Sex.*
Note: Thick black Lines Denote Average Coefficients of the two Groups

The results presented in Figure 22 indicate a trend that interindividual differences in the strength of the intraindividual couplings could differ between the sexes. Across groups there was a small trend indicating that correlation coefficients were more positive for males than for females and for older adults than for young adults. In the following, multi-level models are used to examine whether these trends were statistically significant.

5.5.2 Multi-Level Coupling of Day-to-Day Processing Fluctuations in Postural Control and Working Memory

In this section, a number of multi-level models are reported that were used to investigate intraindividual couplings across domains and interindividual differences in these. All multi-level models included the trend model of simple standing postural control and examined whether day-to-day processing fluctuations in WM explained intraindividual variance above trends in postural control performance. The control of trends and the effect of day-to-day processing fluctuations in WM were estimated within the same model to account for potential interdependencies. The trend model of simple standing postural control contained a linear trend (Linear) and a quadratic trend (Quadratic), and random variance parameters of the intercept, linear and quadratic trends, and a covariance between the linear and quadratic trends. All models further contained a dummy-coded age effect (i.e., young adults were coded with 1, older adults with 2) on the intercept in order to take age differences in the average performance into account.

In a first model, the average effect of processing fluctuations in WM on processing fluctuations was estimated and it's significance was tested. In this respect, a fixed and random effect of processing fluctuations in WM were inserted as an additional predictor in the time-model of simple standing before the χ^2 differences of the two models were compared. The inclusion of processing fluctuations in WM significantly predicted intraindividual variations in postural control beyond the intraindividual trends. An increase in WM reaction time of 100 ms was significantly associated with an increase in postural control COP area of about 5.75 mm^2, $\chi^2(2) = 126.5, p < .05$.

5.5.2.1 No Age Interactions in Cross-Domain Couplings of Processing Fluctuations

In the first multi-level model the fixed effect of day-to-day processing fluctuations in working memory (Day-to-Day WM) was inserted in the trend model of simple standing and tested for statistical significance. Subsequently, interindividual differences in the relationship between day-to-day fluctuations in simple standing and WM were examined (i.e., statistical significance test of the second-level random variance of Day-to-Day WM). In a final step, it was examined whether interindividual differences in the relationship between processing fluctuations in working memory and postural control were associated with age group. The results of these analyses can be seen in Table 8. It is important to note that Table 8 reports only the values of the parameters in the final model.

The final model was arrived at using the following equations:

First Level: $Y_{ij} = \pi_{0i} + \pi_{1i}(\text{Linear}) + \pi_{2i}(\text{Quadratic}) + \pi_{3i}(\text{Day-to-Day WM}) + \varepsilon_{ij}$

Second Level: $\pi_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \zeta_{0i}$

$\pi_{1i} = \gamma_{10} + \zeta_{1i}$

$\pi_{2i} = \gamma_{20} + \zeta_{2i}$

$\pi_{3i} = \gamma_{30} + \gamma_{31}(\text{Age}) + \zeta_{3i}$

Where $\varepsilon_{ij} \sim N(0, \sigma_\varepsilon^2)$ and $\begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix} \times \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix}^t \approx N \begin{bmatrix} \sigma_0^2 & 0 & 0 & 0 \\ 0 & \sigma_1^2 & \sigma_{12} & 0 \\ 0 & \sigma_{21} & \sigma_2^2 & 0 \\ 0 & 0 & 0 & \sigma_3^2 \end{bmatrix}$

Table 8. *Multi-Level Modeling of the Effect of Day-to-Day Processing Fluctuations in Working Memory on Processing Fluctuations in Postural Control: The Effect of Age Group*

		Parameter	**Value**	**Model Change**
Fixed Effects				
Average	Intercept	γ_{00}	145.67	
	Age	γ_{01}	200.78	$\chi^2(1) = 12.0; p < .05$
Linear	Intercept	γ_{10}	-54.07	
Quadratic	Intercept	γ_{20}	65.40	
Day-to-Day WM	Intercept	γ_{30}	1.67	$\chi^2(1) = 124.5; p < .05$
	Age	γ_{31}	5.55	$\chi^2(1) = 0.6; p > .10$
Random Effects (Variance Components)				
Level 1	Within-Person	σ_ε^2	3002.32	
	In Average	σ_0^2	25179	
	In Linear	σ_1^2	3548.27	
Level 2	In Quadratic	σ_2^2	32041	
	In Day-to-Day WM	σ_3^2	106.25	$\chi^2(1) = 2.0; p > .10$
	In Linear by Quadratic	σ_{21}	-6414.14	

Multi-level modeling analyses showed that day-to-day processing fluctuations in WM significantly predicted intraindividual variance in simple standing postural control above the effects of trends (as indicated by the significant fixed effect of Day-to-Day WM). The random variance around the fixed effect was, however, not significant, which could be a consequence of the relatively small number of units of analysis at level two (i.e., participants). The interaction between age group and the strength of the cross-domain relationship was examined although the random variance of the effect of day-to-day fluctuations was not significant. Counter to predictions, the age interaction was not significant. Note, however, that the estimated age difference was in the expected direction. In the young adult group a deviance of 100 ms from the exponential learning curve lead to an increase of 1.62 mm^2 in COP-area. In the older adult group, the same deviance was associated with an increase of 7.77 mm^2.

5.5.2.2 Interactions of Level of Postural Control and Working Memory in Cross-Domain Couplings

Concerning age differences in intraindividual cross-domain couplings it was assumed that declines in the postural control system of older adults leads to a higher vulnerability to processing fluctuations in attentional control and that the aged cognitive system produces higher levels of processing fluctuations. One could argue that age group, implemented here as binary a variable, is only a proxy of the status of the efficacy of the postural control and cognitive system. The correlation of the age group variable with the level of postural control indicated by the level of moment-to-moment fluctuations across days was .54 (*p* < .05), which implies that about 29.5 % of the interindividual variance in postural control was related to age group. Correlating age group with interindividual differences in WM was .72 (*p* < .05), which indicated that about 52 % of the interindividual differences in the overall WM reaction time performance was related to age group.

In multi-level analyses, it was examined whether the overall level of moment-to-moment processing fluctuations in postural control across days (Mean Posture) and the overall level of WM reaction-time performance across days (Mean WM) interacted with interindividual differences in the strength of the intraindividual cross-domain couplings. Parameter tests were conducted with model comparisons. Mean Posture and Mean WM were introduced as interaction terms on the intraindividual regression coefficients of day-to-day fluctuations in working memory (Day-to-Day WM) predicting postural control performance. Both interactions were tested against a model without any interaction term because there was no *a priori* theoretical rational to decide the order of the effects. In a final step, it was tested if the interaction of Mean Posture and Mean WM (Posture*WM) influenced the intraindividual relationship of processing fluctuations in postural control and working memory. The fixed effect of the Mean-Posture-by-Mean-WM interaction was tested against a model containing both simple interaction terms. This interaction was examined to answer the question whether individuals with particularly bad performances in postural control and working memory would show a more pronounced intraindividual coupling than could be predicted by the two simple interactions. Table 9 shows the results of the series of multi-level models described above. It is important to note that the parameter values provided in Table 9 were taken from the final model. Mean Posture and Mean WM were centered with respect to their respective grand means across all participants and divided by 100. The parameter values of the fixed effect of Day-to-Day WM corresponds, therefore, to the strength of the cross-domain relationship at the grand mean of Mean Posture and Mean WM. As a consequence of the division by 100, interaction effects are expressed as increase in postural control in mm^2 per 100 mm^2 deviance from the grand mean of Mean Posture or per 100 ms deviance from the grand mean of Mean WM, respectively.

The final model was arrived at using the following equations:

First Level: $Y_{ij} = \pi_{0i} + \pi_{1i}(\text{Linear}) + \pi_{2i}(\text{Quadratic}) + \pi_{3i}(\text{Day-to-Day WM}) + \varepsilon_{ij}$

Second Level: $\pi_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \zeta_{0i}$

$\pi_{1i} = \gamma_{10} + \zeta_{1i}$

$\pi_{2i} = \gamma_{20} + \zeta_{2i}$

$\pi_{3i} = \gamma_{30} + \gamma_{31}(\text{Mean Posture}) + \gamma_{32}(\text{Mean WM}) + \gamma_{33}(\text{Posture*WM}) + \zeta_{3i}$

Where $\varepsilon_{ij} \sim N(0, \sigma_\varepsilon^2)$ and $\begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix} \times \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix}^t \approx N \begin{bmatrix} \sigma_0^2 & 0 & 0 & 0 \\ 0 & \sigma_1^2 & \sigma_{12} & 0 \\ 0 & \sigma_{21} & \sigma_2^2 & 0 \\ 0 & 0 & 0 & \sigma_3^2 \end{bmatrix}$

Table 9. *Multi-Level Modeling of the Effect of Day-to-Day Processing Fluctuations in Working Memory on Processing Fluctuations in Postural Control: Testing Interactions of Daily Average Performances in Postural Control and Working Memory*

		Parameter	**Value**	**Model Change**
Fixed Effects				
Average	Intercept	γ_{00}	145.65	
	Age	γ_{01}	200.81	
Linear	Intercept	γ_{10}	-54.17	
Quadratic	Intercept	γ_{20}	65.62	
Day-to-Day WM	Intercept	γ_{30}	8.76	
	Mean Posture	γ_{31}	6.38	$\chi^2(1) = 5.2; p < .05$
	Mean WM	γ_{32}	-1.78	$\chi^2(1) = 1.2; p > .10$
	Posture*WM	γ_{33}	-0.64	$\chi^2(1) = 0.2; p > .10$
Random Effects (Variance Components)				
Level 1	Within-Person	σ_ε^2	2985.52	
	In Average	σ_0^2	25105	
	In Linear	σ_1^2	3535.87	
Level 2	In Quadratic	σ_2^2	-6505.33	
	In Day-to-Day WM	σ_3^2	141.99	
	In Linear by Quadratic	σ_{21}	-6505.33	

The results of the multi-level modeling analyses showed that interindividual differences in the overall level of working memory performances did not significantly predict interindividual differences in the strength of intraindividual cross-domain couplings. However, individuals who on average performed worse in postural control also showed stronger intraindividual cross-domain couplings than individuals with better postural control performance. This relationship was not statistically stronger for individuals who combined relatively bad postural control performances with relatively bad WM performance. Although the interaction of the average daily level of WM performance as well as the interaction of mean postural control by mean WM on the intraindividual cross-domain couplings were not significant, they nevertheless influenced the parameter values of the other fixed effects due to the centering. Therefore, these interactions were omitted from the model to obtain adequate estimations of the model parameters. Results are displayed in Table 10.

The final model was arrived at using the following equations:

First Level: $Y_{ij} = \pi_{0i} + \pi_{1i}(\text{Linear}) + \pi_{2i}(\text{Quadratic}) + \pi_{3i}(\text{Day-to-Day WM}) + \varepsilon_{ij}$

Second Level: $\pi_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \zeta_{0i}$

$\pi_{1i} = \gamma_{10} + \zeta_{1i}$

$\pi_{2i} = \gamma_{20} + \zeta_{2i}$

$\pi_{3i} = \gamma_{30} + \gamma_{31}(\text{Mean Posture}) + \zeta_{3i}$

Where $\varepsilon_{ij} \sim N(0, \sigma_\varepsilon^2)$ and

$$\begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix} \times \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix}^t \approx N \begin{bmatrix} \sigma_0^2 & 0 & 0 & 0 \\ 0 & \sigma_1^2 & \sigma_{12} & 0 \\ 0 & \sigma_{21} & \sigma_2^2 & 0 \\ 0 & 0 & 0 & \sigma_3^2 \end{bmatrix}$$

Table 10. *Multi-Level Modeling of the Effect of Day-to-Day Processing Fluctuations in Working Memory on Processing Fluctuations in Postural Control Including an Interaction of Daily Average Performances in Postural Control: Final Model Parameters*

		Parameter	Value	Model Change
Fixed Effects				
Average	Intercept	γ_{00}	145.67	
	Age	γ_{01}	200.73	
Linear	Intercept	γ_{10}	-54.13	
Quadratic	Intercept	γ_{20}	65.56	
Day-to-Day WM	Intercept	γ_{30}	4.94	
	Mean Posture	γ_{31}	4.78	$\chi^2(1) = 5.2; p < .05$
Random Effects (Variance Components)				
Level 1	Within-Person	σ_ε^2	2992.55	
	In Average	σ_0^2	25139	
	In Linear	σ_1^2	3531.58	
Level 2	In Quadratic	σ_2^2	31702	
	In Day-to-Day WM	σ_3^2	116.81	
	In Linear by Quadratic	σ_{21}	-6489.78	

The final model parameters indicated that on average a processing fluctuation of 100 ms on a given day was associated with an increase of 4.94 mm^2 in postural control. Individuals that deviated by 100 mm^2 from the grand mean in average postural control performance across days demonstrated an intraindividual cross-domain coupling that was 4.78 mm^2 per 100 ms deviance lower or higher than for the average postural control performer. Figure 23 illustrates what the interaction between interindividual differences in the daily average of moment-to-moment processing fluctuations and the strength of the intraindividual cross-domains couplings implies. Young women, young men, older women, and older men differ in the level of moment-to-moment processing fluctuations. The average change in postural control performance in relation to processing fluctuations in WM was calculated for each of these groups based on the parameter values obtained the analysis. The illustration of the level of moment-to-moment fluctuations by strength of cross-domain interaction in Figure 23 demonstrates that older adults and males should react stronger in their postural control performance in response to the same nominal processing fluctuation in WM than young adults and females.

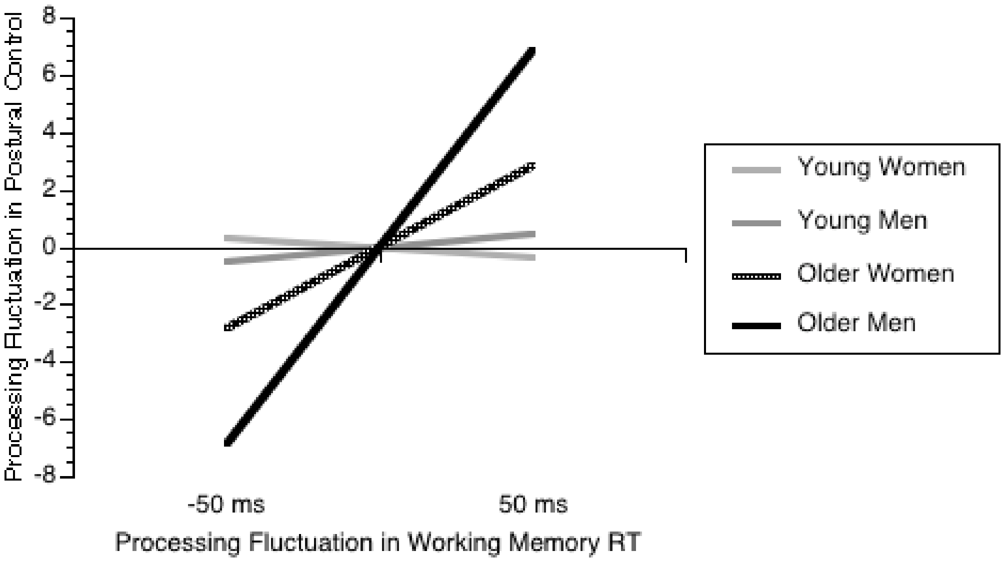

Figure 23. *Estimated Group Differences in Intraindividual Cross-Domain Couplings as Predicted by an Interaction Between Level of Moment-to-Moment Fluctuations in Postural Control and Strength of Intra-individual Coupling.*

5.5.2.3 Interactions of Age and Sex in Cross-Domain Couplings: Older Males Differ

In the following it is examined whether age or sex, or a combination of both predicted interindividual differences in the strength of the intraindividual cross-domain coupling. In order to do this, multi-level analyses were conducted that introduced age group (Age) and sex (Sex) as dummy variables (i.e., young adults = 0; older adults = 1; women = 0; men =1). The age and sex interactions were tested against a model without including such parameters. In a final step, the age-by-sex interaction (Age*Sex) on the coupling parameter was tested against a model including both simple interaction terms in order to examine if older males showed a stronger coupling than could be predicted by the simple effects of age and sex. The simple effects of age and sex on the average postural control performance were also included in the model but not examined statistically.[13] Table 11 displays the results of these multi-level analyses. Only the final model parameter values are given here.

The final model was arrived at using the following equations:

First Level: $Y_{ij} = \pi_{0i} + \pi_{1i}(\text{Linear}) + \pi_{2i}(\text{Quadratic}) + \pi_{3i}(\text{Day-to-Day WM}) + \varepsilon_{ij}$

Second Level: $\pi_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \gamma_{02}(\text{Sex}) + \zeta_{0i}$

$\pi_{1i} = \gamma_{10} + \zeta_{1i}$

$\pi_{2i} = \gamma_{20} + \zeta_{2i}$

$\pi_{3i} = \gamma_{30} + \gamma_{31}(\text{Age}) + \gamma_{32}(\text{Sex}) + \gamma_{33}(\text{Age*Sex}) + \zeta_{3i}$

Where $\varepsilon_{ij} \sim N(0, \sigma_\varepsilon^2)$ and $\begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix} \times \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix}^t \approx N \begin{bmatrix} \sigma_0^2 & 0 & 0 & 0 \\ 0 & \sigma_1^2 & \sigma_{12} & 0 \\ 0 & \sigma_{21} & \sigma_2^2 & 0 \\ 0 & 0 & 0 & \sigma_3^2 \end{bmatrix}$

Table 11. *Multi-Level Modeling of the Effect of Day-to-Day Processing Fluctuations in Working Memory on Processing Fluctuations in Postural Control: Testing Interactions of Age Group and Sex*

		Parameter	Value	Model Change
Fixed Effects				
Average	Intercept	γ_{00}	97.17	
	Age	γ_{01}	200.72	
	Sex	γ_{02}	96.97	
Linear	Intercept	γ_{10}	-53.98	
Quadratic	Intercept	γ_{20}	65.78	
Day-to-Day WM	Intercept	γ_{30}	1.06	
	Age	γ_{31}	-0.25	$\chi^2(1) = 0.6; p > .10$
	Sex	γ_{32}	0.18	$\chi^2(1) = 2.2; p > .10$
	Age*Sex	γ_{33}	13.41	$\chi^2(1) = 1.0; p > .10$
Random Effects (Variance Components)				
Level 1	Within-Person	σ_ε^2	3003.34	
	In Average	σ_0^2	22801	
	In Linear	σ_1^2	3503.25	
Level 2	In Quadratic	σ_2^2	31847	
	In Day-to-Day WM	σ_3^2	75.19	
	In Linear by Quadratic	σ_{21}	-6442	

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[13] The fixed effects of age and sex on average postural control performance were not tested statistically because earlier ANOVA analyses reported in section 5.2.1 had already shown that age and sex were significantly related to average moment-to-moment fluctuations and that both effects did not interact.

The results of the multi-level analyses of potential age and sex interactions on the intraindividual cross-domain couplings showed that neither the simple interactions nor the interaction combining both factors were statistically significant. The estimated average couplings within each of the four age-by-sex groups were, however, very interesting. Figure 24 illustrates the estimated average cross-domain intraindividual couplings.

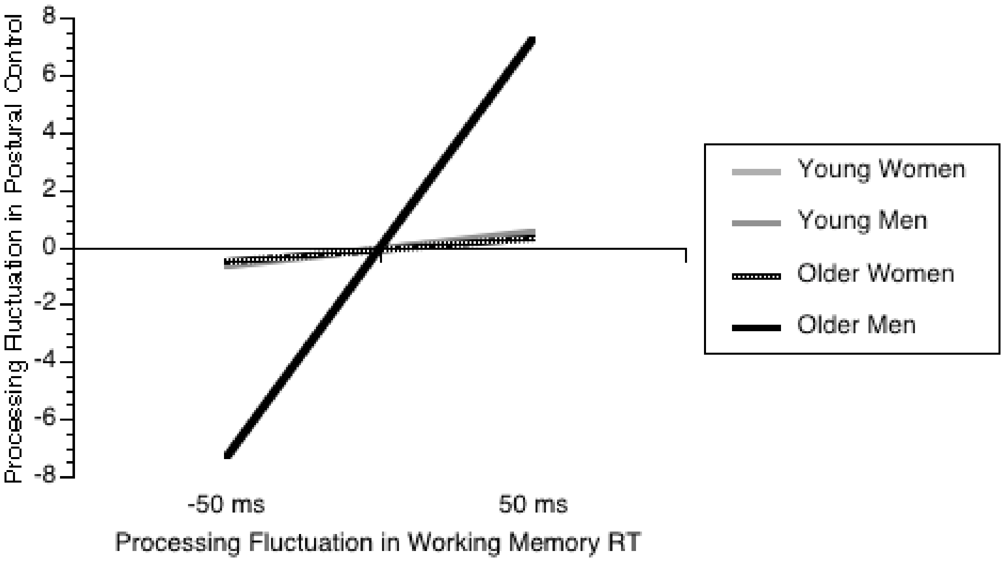

Figure 24. *Estimated Age Group and Sex Differences in Intraindividual Cross-Domain Couplings.*

The illustration of the estimated effects of age and sex on the intraindividual cross-domain couplings demonstrated that only the older males showed on average a marked influence of processing fluctuations in WM on their postural control performance. As a matter of fact, the intraindividual couplings in the other three groups were at least visually indistinguishable from each other and close to zero. In the Hypothesis section it was argued that in particular older men might be in need of attentional control to improve sensory integration processes. Thus, it was investigated in the final multi-level model whether the strength of the intraindividual coupling in older men was statistically different from the average coupling of the other three groups. A dummy variable ("OlderMen") that was coded as 1 for the older males and 0 for the other groups was introduced as an interaction term on the cross-domain coupling parameter (Day-to-Day WM). The results are displayed in Table 12.

The final model was arrived at using the following equations:

First Level: $Y_{ij} = \pi_{0i} + \pi_{1i}(\text{Linear}) + \pi_{2i}(\text{Quadratic}) + \pi_{3i}(\text{Day-to-Day WM}) + \varepsilon_{ij}$

Second Level: $\pi_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \gamma_{02}(\text{Sex}) + \zeta_{0i}$

$\pi_{1i} = \gamma_{10} + \zeta_{1i}$

$\pi_{2i} = \gamma_{20} + \zeta_{2i}$

$\pi_{3i} = \gamma_{30} + \gamma_{31}(\text{OlderMen}) + \zeta_{3i}$

Where $\varepsilon_{ij} \sim N(0, \sigma_\varepsilon^2)$ and

$$\begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix} \times \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \\ \zeta_{2i} \\ \zeta_{3i} \end{bmatrix}^t \approx N \begin{bmatrix} \sigma_0^2 & 0 & 0 & 0 \\ 0 & \sigma_1^2 & \sigma_{12} & 0 \\ 0 & \sigma_{21} & \sigma_2^2 & 0 \\ 0 & 0 & 0 & \sigma_3^2 \end{bmatrix}$$

Table 12. *Multi-Level Modeling of the Effect of Day-to-Day Processing Fluctuations in Working Memory on Processing Fluctuations in Postural Control: Couplings in Older Males*

		Parameter	Value	Model Change
Fixed Effects				
Average	Intercept	γ_{00}	97.17	
	Age	γ_{01}	200.71	
	Sex	γ_{02}	96.98	
Linear	Intercept	γ_{10}	-53.99	
Quadratic	Intercept	γ_{20}	65.78	
Day-to-Day WM	Intercept	γ_{30}	0.94	
	OlderMen	γ_{31}	13.44	$\chi^2(1) = 4.0; p < .05$
Random Effects (Variance Components)				
Level 1	Within-Person	σ_ε^2	3003.4	
	In Average	σ_0^2	22801	
	In Linear	σ_1^2	0	
Level 2	In Quadratic	σ_2^2	3504.04	
	In Day-to-Day WM	σ_3^2	74.77	
	In Linear by Quadratic	σ_{21}	-6440.12	

Table 12 shows that the intraindividual coupling between day-to-day processing fluctuations in postural control and working memory was stronger in the older men than the average of the three other groups. A processing fluctuation in working memory of 100 ms on a given day was associated with a decrease in postural control of 14.38 mm^2 in older males, whereas the average decrease in the other three groups amounted only to 0.94 mm^2.