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Research Article

The Association Between the Kyphosis Angle and Physical Performance in Community-Dwelling Older Adults

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Abstract

Background: We investigated prospectively among community-dwelling older adults aged 65 years and older whether a larger kyphosis angle is associated with poorer physical performance (balance, muscle strength, or both), and whether this association is unidirectional.

Methods: Male and female participants performed a multicomponent physical performance test with subscores for gait, muscle strength, and balance at baseline and after 2 years. Hand grip strength was also measured at baseline and at follow-up. The Cobb angle was measured on DXA-based Vertebral Fracture Assessments, made at the baseline and follow-up visit. Through linear and logistic regression analysis, we investigated the association between the kyphosis angle and physical performance and vice versa. We stratified for sex, and tested for effect modification by age and study center.

Results: The mean kyphosis angle was 37° and 15% of the participants (n = 1 220, mean age 72.9 ± 5.7 years) had hyperkyphosis (Cobb angle ≥50°). A larger kyphosis angle at baseline was independently associated with a poorer total physical performance score in women of the oldest quartile (≥77 years) in both the cross-sectional and longitudinal analyses (baseline B −0.32, 95% confidence interval [CI] −0.56–0.08; follow-up B 0.32, 95% CI −0.55–0.10). There was no association between physical performance at baseline and kyphosis progression.

Conclusion: A larger kyphosis angle is independently associated with a poorer physical performance at baseline and over time, and the direction of this association is unidirectional. These results emphasize the importance of early detection and treatment of hyperkyphosis to prevent further worsening of the kyphosis angle, thereby potentially preserving physical performance.

Keywords: Balance, Cobb angle, Muscle, Physical performance, Successful aging

The kyphosis angle of the thoracic spine increases with aging (1). A kyphosis angle transcending normal ranges, is defined as hyperkyphosis. Commonly, hyperkyphosis is defined as a kyphosis angle of 50° or more, although a threshold of 40° has also been used (2,3). Depending on population and definition, hyperkyphosis is prevalent in 15%–40% of the community-dwelling older adults (4–6) and is associated with negative health consequences like higher mortality rates and a doubled fall risk (7,8). Previous studies showed that a larger kyphosis angle may be associated with lower physical performance (5,9–15), which in turn is strongly associated with disability, lower quality of life and mortality in older adults (16,17).

Nevertheless, because the majority of studies regarding the association between the kyphosis angle and physical performance were cross-sectional, it is not known if a larger kyphosis angle leads to a decrease in physical performance or if—conversely—lower physical performance leads to an increase of the kyphosis angle. Studies on the association between physical performance and the kyphosis angle are scant and have contradicting results (14,18–20). Sugai et al. reported that lower gait speed is independently associated with kyphosis progression (18), whereas Kado et al. found no association between gait speed and baseline kyphosis or kyphosis progression (14). Lower back extensor muscle strength has been shown to be associated with the incidence of vertebral fractures and a larger kyphosis angle (19,20). Muscle weakness in older persons is more likely to be generalized than to be site-specific and limited to the spinal extensors. Therefore, reduced muscle strength as part of a poorer physical performance may lead to a larger kyphosis angle.

Only 2 studies investigated the association between the kyphosis angle and physical performance prospectively, with different results (10,15). Lorbergs et al. found no association between a larger kyphosis angle and physical performance after 3.4 years in men and women with a mean age of 61 ± 8 years (15). In contrast, Katzman et al. showed in a slightly older group of women with a mean age of 68 ± 6 years, that a larger kyphosis angle was associated with longer Timed Up and Go times at baseline and after follow-up as well as a larger increase of Timed Up and Go times during follow-up (4.4 years) (10). Although the Timed Up and Go Test gives an indication of overall physical performance, by measuring the time needed to get up, walk 3 meters forth and back and get seated again, no information can be derived whether a person experiences difficulties in any specific component of physical performance, and if so, in which one. Furthermore, these studies did not include a balance test. Knowing whether a larger kyphosis angle is associated with balance, gait or muscle strength, would enhance our insight in the pathophysiological mechanism underlying the association between a larger kyphosis angle and lower physical performance, and may lead to targeted interventions to reduce progression of the kyphosis angle. More prospective studies are warranted in both women and men to unravel the association between the kyphosis angle and the components of physical performance, that is, gait, muscle strength, and balance.

Therefore, we used a multicomponent physical performance test with subscores for gait, muscle strength, and balance and measured hand grip strength to investigate prospectively and bidirectionally the association between the kyphosis angle and physical performance in a cohort of Dutch community-dwelling men and women, aged 65 years and older.

Method

Participants

A subsample of the B-vitamins for the PRevention Of Osteoporotic Fractures (B-PROOF) study, in whom a dual-energy X-ray assessment (DXA) was available (n = 1 220), was eligible for the current study. The B-PROOF is a multicenter randomized controlled intervention study designed to investigate whether vitamin B_{12} and folic acid supplementation reduces osteoporotic fracture incidence in older individuals with a mildly elevated homocysteine level. The intervention did not influence osteoporotic fractures, falls, or physical performance (21). Therefore, we treated the study population as a cohort in our current study. Community-dwelling older adults, aged 65 years and older, with mildly elevated plasma homocysteine level (≥12 μmol/L) participated in this study. The inclusion period was from August 2008 to March 2011. The selection procedure is described in detail in the study design paper of the B-PROOF study (22). At baseline and at the follow-up visit after 2 years, the participants underwent physical performance tests and a DXA scan. The study was conducted according to the principles described in the Declaration of Helsinki. The Wageningen University Medical Ethics Committee approved the study protocol, and the committees of the two study centers, VU University Medical Center and Erasmus Medical Center, confirmed this approval. All participants gave written informed consent.

Data Collection

Cobb angle

We determined the kyphosis angle of the thoracic spine by measuring the Cobb angle. The Cobb angle is currently considered to be the gold standard kyphosis measurement method and is commonly measured between the superior endplate of the fourth and the inferior endplate of the 12th thoracic vertebra (23). We defined hyperkyphosis as a Cobb angle ≥50°, as this definition is commonly used in research (12,24). Two researchers (S.B. and I.M.H.) measured the Cobb angle independently on the DXA-based Vertebral Fracture Assessment, made at baseline and at the follow-up visit in recumbent position (7,25). If there was a difference between the 2 measurements of the Cobb angle of less than 10°, we calculated the mean value. A third expert researcher (H.C.W.) remeasured the Cobb angle if the difference was 10° or more, or if the Cobb angle was judged to be more than 50° by 1 researcher and less than 50° by the other researcher. Based on consensus, 2 researchers (H.C.W. and M.C.K.) decided on the final value of the Cobb angle.

Physical performance and hand grip strength

Participants performed a validated physical performance test consisting of the components gait speed, chair stands, and balance (26). To measure gait speed, participants walked as quickly as possible three meters back and forth. During the chair stands test, participants rose from a chair and sat down again 5 times in a row without using their arms. We tested balance by measuring how long participants were able to stand with one foot in front of the other—the tandem stand—with a maximum of 10 seconds. The time needed to walk and to perform the chair stands and balance test was translated into a score, ranging from 0 to 4 points. These subscores combined, formed the total performance score, ranging from a minimum score of zero points to a maximum score of twelve points.

The total performance score was the primary outcome in this study. Secondary outcomes of physical performance were the balance test score, the hand grip strength, and the change in the balance test score and hand grip strength over time. Hand grip strength is a measure of general muscle strength and has been shown to be correlated to back extensor muscle strength (27,28). Hand grip strength was measured with a strain-gauged dynamometer (Takei, TKK 5401, Takei Scientific Instruments Co. Ltd., Niigata City, Japan), and recorded the maximal result of 4 trials, namely 2 per hand.

Covariables

At baseline, we obtained age, sex, educational level, current alcohol intake, current or former smoking, medical history regarding fractures and osteoporosis, and information on the use of a walking aid through structured questionnaires. Height, weight, and 25-hydroxyvitamin D status were measured. Cognitive function was determined using the Mini-Mental State Examination (MMSE) (29), and the Geriatric Depression Scale (GDS) (30) was used to measure depressive symptoms. To quantify daily physical activity, we used the validated LASA Physical Activity Questionnaire, with daily physical activity expressed in both minutes per day and kilocalories per day (31). Treatment allocation of the original trial and the study center in which the participant was included was recorded.

Statistical analysis

Baseline characteristics of female and male participants were compared through a chi-square test for categorical and an independent Student's *t* test for continuous data. If the distribution was skewed, we used nonparametric tests.

Association between the kyphosis angle at baseline and physical performance at baseline and over time

Linear regression analysis was performed to investigate the association between the kyphosis angle and the total physical performance score and hand grip strength. Because of a ceiling effect in the balance test, with 75% of the participants having a maximal score, we used binary logistic regression to investigate the association between hyperkyphosis and balance. We divided the scores into normal (able to hold tandem position for at least 10 seconds) and too low (tandem position maintained for less than 10 seconds).

Association between the kyphosis angle at baseline and change of physical performance over time

Linear regression analysis was performed to investigate the association between the kyphosis angle and the change in the total physical performance score and hand grip strength at the follow-up visit. Through binary logistic regression, we investigated the association between hyperkyphosis and the change of the balance test score at the follow-up visit.

Association between increase of the kyphosis angle over time and physical performance at follow-up

The association between increase of the kyphosis angle during follow-up and physical performance were investigated through binary logistic regression analysis.

Association between physical performance at baseline and increase of the kyphosis angle over time

Based on interrater reliability and intrarater reliability in the literature (32,33), and our own cohorts (data not published) of 3.2°–4.5°, we interpreted an increase in the Cobb angle of at least 5° during the follow-up as the minimal detectable difference.

Statistical models

A priori, we decided to stratify for sex in all analyses, as overlapping results between the women with the best performance and men with the worst performance may lead to a type II error. We tested for interaction with age and study center. If the *p* value of interaction was 0.10 or below, we performed stratified analyses. In case of stratification, relevant baseline characteristics between the 2 groups were compared.

We adjusted the univariate model for potential confounders, that is, body mass index, current or former smoking, alcohol use, fracture after the age of 50, vitamin D level, and treatment allocation of the original trial. The variables age or study center were added to the univariate model, if there was no indication that these variables were effect modifiers. The use of a walking aid was not added to the model because of too much correlation with the outcome: physical performance.

Hyperkyphosis may lead to difficulties to move and exercise, and thereby restrain physical activity. The physical activity level of the participants may thus be a mediator in the association between hyperkyphosis and physical performance. Therefore, we tested mediation by the method of Hayes and Rockwood (34).

Level of significance was set at $\alpha = 0.05$. Statistical analyses were performed with SPSS software (Statistical Package for the Social Sciences), version 21.0.

Results

Baseline characteristics are shown in Table 1. The results of the analyses, regarding the association between the kyphosis angle and physical performance, are presented in Tables 2–4.

The 1 212 participants had a mean age of 72.9 ± 5.7 years. At baseline, the mean Cobb angle was 37.0° ± 11.9°, with a mean Cobb angle of 39.5 ± 11.9° in female participants and 34.6 ± 11.4° in male participants ($p < .001$). Hyperkyphosis was present in 15% of the participants both at baseline and at the follow-up visit, with a significant difference between female and male participants: 22% of the female participants and 10% of the male participants had hyperkyphosis ($p < .001$). Mean change of the Cobb angle over time was 0.46° ± 5.7°. Compared to male participants, female participants used a walking aid twice as often (10% vs 4%, $p < .001$) yet females reported to be more physically active than men in this cohort ($p < .001$).

At baseline, the median of the total physical performance score was 9 out of 12 points (interquartile range [IQR] 7–11 points), and 27% of the participants had an abnormal balance test. The mean grip strength was 33.1 ± 10.2 kg. Data on physical performance at the follow-up visit were present in 90%–95% of the participants (Supplementary Figure 1). At follow-up, the median of the total physical performance score was also 9 out of 12 points (IQR 6–11 points). A Cobb angle at follow-up was available in 1 104 participants (90%). The mean of the Cobb angle at follow-up was almost equal to the mean at baseline: 37.5° ±11.8°.

Association Between the Kyphosis Angle at Baseline and Physical Performance at Baseline

The kyphosis angle was negatively associated with the total physical performance score in the total cohort (B −0.18, 95% confidence interval [CI] −0.25–0.11, $p < .001$). In the stratified analyses, this association remained significant in women of the oldest quartile of this cohort, aged 77 years and older. For each 5-degree increment of the kyphosis angle at baseline, the total performance score was 0.32 points lower in the adjusted models (B −0.32, 95% CI −0.56–0.08, $p = .009$).

In the total cohort, the kyphosis angle at baseline was negatively associated with the balance subscore in the adjusted model. After stratification for age and sex, this association remained significant in women of the oldest quartile of this cohort. The kyphosis angle at baseline was also negatively associated with hand grip strength in the total cohort. After stratification for sex, the association remained significant in both men and women (in men B −0.46, 95%

Table 1. Baseline Characteristics

Baseline Characteristics	All (*n* = 1 212)	Female (*n* = 584)	Male (*n* = 628)	*p* Value
Age (years, *SD*)	72.9 ± 5.7	72.8 ± 5.7	73.0 ± 5.6	.542
Study center (*n*, %)				<.001
Erasmus Medical Center	793 (65%)	346 (59%)	447 (71%)	
VU Medical Center	419 (35%)	238 (41%)	181 (29%)	
Education level (*n*, %)				<.001
Low	652 (54%)	372 (64%)	280 (45%)	
Intermediate	241 (20%)	104 (18%)	137 (22%)	
High	317 (26%)	107 (18%)	210 (33%)	
Current or former smoker (*n*, %)	806 (67%)	305 (52%)	501 (80%)	<.001
Alcohol use ≥3 units per day (*n*, %)	56 (5%)	9 (2%)	47 (8%)	<.001
Cardiovascular comorbidity (*n*, %)	340 (30%)	142 (24%)	198 (32%)	.017
Number of prescriptions (median, IQR)	3.0 (1.0–5.0)	3.0 (1.0–5.0)	2.0 (1.0–4.0)	.039
BMI (kg/m²; mean, *SD*)	27.0 ± 3.8	27.2 ± 4.4	26.8 ± 3.2	.081
MMSE-score (median, IQR)	28 (27–29)	29 (28–30)	28 (27–29)	<.001
GDS-15-score (median, IQR)	1 (0–2)	1 (0–2)	1 (0–2)	.006
Vitamin D level (nmol/L; mean, *SD*)	55.0 ± 23.6	54.8 ± 24.0	55.3 ± 23.3	.710
Fracture after the age of 50 (*n*, %)	281 (23%)	196 (34%)	85 (14%)	<.001
Vertebral fractures				
≥1 fracture present (*n*, %)	289 (24%)	144 (25%)	145 (23%)	.499
Use of walking aid (*n*, %)	85 (7%)	61 (10%)	24 (4%)	<.001
Physical activity (min/day; mean, *SD*)	161 ± 105	174 ± 98	148 ± 110	<.001
Cobb angle in degrees (mean, *SD*)	37 ± 11.9	39.5 ± 11.9	34.6 ± 11.4	<.001
Hyperkyphosis (*n*, %)	182 (15%)	126 (22%)	60 (10%)	<.001

Notes: BMI = body mass index; GDS = Geriatric Depression Scale; IQR = interquartile range; MMSE = Mini-Mental State Examination; *SD* = standard deviation.

Table 2. The Association Between the Kyphosis Angle and the Total Physical Performance Score

	Baseline Visit‡	Follow-up Visit‡	Decline During Follow-up§
Total Performance Score†	B (95% CI)	B (95% CI)	B (95% CI)
Total cohort	−0.18 (−0.25–0.11)***	−0.19 (−0.27–0.11)***	0.01 (−0.06–0.01)
Females ≥77 years	−0.32 (−0.56–0.08)**	−0.32 (−0.55–0.10)**	−0.22 (−0.43–0.01)*
Males ≥77 years	0.03 (−0.19–0.24)	0.04 (−0.17–0.25)	−0.10 (−0.29–0.09)
Females <77 years	−0.08 (−0.22–0.07)	−0.07 (−0.22–0.07)	0.09 (−0.02–0.21)
Males <77 years	0.00 (−0.11–0.11)	0.00 (−0.11–0.11)	−0.02 (−0.13–0.09)

Notes: BMI = body mass index; CI = confidence interval.

p Value: $^{***}p \le .001$; $^{**}p \le .01$; $^{*}p \le .1$.

†The total performance score consisted of a balance test, chair stands test and gait speed. Each subscore ranged from 0 to 4 points, adding up to a total performance score of 0–12 points.

‡Corrected for BMI, vitamin D level, and study center.

§Corrected for age.

CI −0.19–0.73, *p* .001; in women B −0.026, 95% CI −0.07–0.46, *p* .001). Physical activity did not mediate the association between the kyphosis angle at baseline and physical performance at baseline.

Association Between the Kyphosis Angle at Baseline and Physical Performance Over Time

The kyphosis angle at baseline was negatively associated with the total physical performance score at the follow-up visit in the total cohort (B −0.19, 95% CI −0.27–0.11, $p < .001$). In the stratified analyses, this association remained significant in women of the oldest quartile of this cohort, aged 77 years and older. For each 5-degree increment of the kyphosis angle at baseline, the total performance score was 0.32 points lower in the adjusted models (B −0.32, 95% CI −0.55–0.10, *p* .006).

The association between the kyphosis angle at baseline and physical performance subscores at the follow-up visit was less uniform. A larger kyphosis angle at baseline was independently associated with impaired performance at follow-up on the balance test in women of the oldest quartile only (odds ratio [OR] 1.75, 95% CI 1.16–2.64, *p* .008). In the total cohort, we found no association between the kyphosis angle and balance. The kyphosis angle at baseline was negatively associated with grip strength (B −0.601, 95% CI −0.835–0.367, $p < .001$) at follow-up in the total cohort in the adjusted analyses. After stratification for sex, there was no association with grip strength at follow-up. Physical activity did not mediate the association between the kyphosis angle at baseline and physical performance over time.

Association Between the Kyphosis Angle at Baseline and Change of Physical Performance Over Time

Although we found no association in the total cohort, in women of the oldest quartile, a larger kyphosis angle at baseline was associated

Table 3. The Association Between the Kyphosis Angle and Balance

	Baseline Visit‡	Follow-up Visit‡	Decline During Follow-up§
Balance Test†	OR (95% CI)	OR (95% CI)	OR (95% CI)
Total cohort	1.90 (1.31–2.76)***	1.31 (0.92–1.87)	0.90 (0.52–1.54)
Stratified analyses (age and gender)			
Females ≥77 years	2.97 (1.35–6.52)**		
Males ≥77 years	1.99 (0.77–5.10)		
Females <77 years	1.32 (0.72–2.43)		
Males <77 years	0.68 (0.23–2.00)		
Stratified analyses (gender)			
Females		1.75 (1.12–2.73)*	0.99 (0.49–2.01)
Males		0.66 (0.34–1.30)	0.73 (0.31–1.71)

Notes: CI = confidence interval; OR = odds ratio.
p Value: *** $p \leq .001$; ** $p \leq .01$; * $p \leq .1$.
†The score of the tandem stand test ranged from 0 to 4 points. For statistical analyses, normale score (tandem stand ≥ 10 seconds, 4 points) was compared with a low score (tandem stand < 10 seconds, 0–3 points).
‡Corrected for vitamin D level, fracture after the age of 50 and study center.
§Corrected for age.

Table 4. The Association Between the Kyphosis Angle and Hand Grip Strength (kg)

	Baseline Visit†	Follow-up Visit‡	Decline During Follow-up†
Hand Grip Strength (kg)	B (95% CI)	B (95% CI)	B (95% CI)
Total cohort	−0.94 (−1.18–0.70)***	−0.60 (−0.84–0.37)***	0.09 (−0.01–0.18)
Females	−0.26 (−0.46–0.07)**	−0.05 (−0.12–0.22)	0.02 (−0.10–0.13)
Males	−0.46 (−0.73–0.19)*	−0.19 (−0.43–0.02)	0.05 (−0.10–0.20)

Notes: CI = confidence interval.
p Value: *** $p \leq .001$; ** $p \leq .01$; * $p \leq .1$.
†Corrected for age, smoking, alcohol use, fracture after the age of 50, and study center.
‡Corrected for age, smoking, alcohol use, and fracture after the age of 50.

with a decline of total physical performance score during follow-up. A 5-degree increment of the kyphosis angle was associated with a decline of the total performance score of 0.22 points (B −0.22, 95% CI −0.43–0.01, *p* .044) which is only just statistically significant.

The kyphosis angle at baseline was not associated with a decrease of the performance of the balance test. The kyphosis angle at baseline was associated with a decrease of hand grip strength in the unadjusted analysis only. Physical activity did not mediate the association between the kyphosis angle at baseline and change of physical performance over time.

Association Between Increase of the Kyphosis Angle Over Time and Physical Performance at Follow-up

Increase of the kyphosis angle during follow-up was neither associated with the total physical performance score (adjusted OR 0.01, 95% CI −0.40–0.41, *p* .969) nor with the physical performance subscores at follow-up. Physical activity did not mediate the association between increase of the kyphosis angle over time and physical performance at follow-up.

Association Between Physical Performance at Baseline and Increase of the Kyphosis Angle Over Time

Thus far, we showed that the kyphosis angle at baseline was associated with poorer physical performance over time. To investigate the direction of this association, we investigated whether physical performance at baseline was associated with increase of the kyphosis angle during follow-up. This association was not present: physical performance at baseline was not associated with the increase of the kyphosis angle during follow-up (total performance score: OR 1.01, 95% CI 0.96–1.07; balance OR 0.99, 95% CI 0.70–1.40; hand grip strength OR 1.00, 95% CI 0.98–1.01).

Discussion

This large prospective cohort study of ambulatory older adults showed that a larger kyphosis angle was independently associated with poorer physical performance, both cross-sectionally and longitudinally. A larger kyphosis angle was associated with both impaired balance and lower muscle strength. After stratification, the association remained significant in women of the oldest quartile, aged 77 years and older. The kyphosis angle was associated with a decline of physical performance during follow-up in women of the oldest quartile only, although this was only just statistically significant. Increase of the kyphosis angle was not associated with physical performance at the follow-up visit. Furthermore, physical performance at baseline was not associated with an increase of the kyphosis angle over time, indicating that the association is unilateral.

To the best of our knowledge, the current study is the first to prospectively investigate the association between the kyphosis angle and physical performance in a cohort of community-dwelling older men and women (65 years and older), closely resembling the general population. The results of the current study are in contrast with the study of Lorbergs et al. which found no association between the kyphosis angle and physical performance (15). This may be explained by the fact that this study population was healthier and much younger, with a mean age of 61 and only included a small subsample aged 65 years and older. Additionally, only a small percentage had hyperkyphosis with a Cobb angle of ≥50°, and the mean Cobb angle was 33°, which is 4° less than the Cobb angle in our current study.

The results of the current study are in line with prior cross-sectional research and the longitudinal study of Katzman et al. (10), consistently showing a lower physical performance in persons with a larger kyphosis angle. The prospective cohort study in women by Katzman et al. (10) reported a 0.007 seconds increase of time needed to perform the Timed Up and Go test in community-dwelling women with osteopenia or osteoporosis with each 5-degree increment of the kyphosis angle (95% CI 0.002–0.01, p .04). Nevertheless, although statistically significant, the effect sizes of this study were so small that the clinical relevance is questionable. In the current study, with each 5 degrees increase of the kyphosis angle, the total performance score was 0.3 points lower, and the score decreased by 0.2 points over 2 years. The minimal important clinical change of the Short Physical Performance Battery, a well-validated physical performance test very similar to the performance test used in the current study, is 0.3 (35–39). Therefore, we assume that the decrease of the physical performance score of 0.3 and 0.2 points is clinically relevant. Decline of physical performance is a multifactorial process, and a larger kyphosis angle is part of that process. The kyphosis angle tends to progress during aging. In 2 cohort studies among older women, the Cobb angle increased with 2.6° in 3 years and 7° in 15 years (10), and 3.9° in 4 years (1). Therefore, ongoing decline of physical performance is to be expected.

Remarkably, in the current study, after stratification the association remained significant only for women of the oldest quartile. Health differences at baseline between men and women or between age groups do not explain this difference within the cohort, as adjustment for comorbidity and physical activity level did not alter the association. Most likely, older women are less able to compensate for the negative consequences of a larger kyphosis angle. A larger kyphosis angle was associated with lower muscle strength and impaired balance. With each vertebral fracture, the kyphosis angle increases with on average 3.8° (14). Increase of the kyphosis angle may induce a forward shift of the center of gravity of the body, if compensation of the posture is insufficient in the lumbar spine and pelvic region. This may diminish the ability to maintain balance (40–42).

This study has several limitations. First, all participants had a slightly elevated homocysteine level, which may limit generalizability of study results. However, in literature no different association is reported between hyperkyphosis and physical performance in normohomocysteinic older adults compared to hyperhomocysteinic older adults. Additionally, in the general population, elevated homocysteine concentrations (≥15 µmol/L) are prevalent in 30%–50% people aged 65 years and older (43–45). Therefore, we think the homocysteine level is unlikely to have an impact on the association between hyperkyphosis and physical performance (40–42).

Second, in this observational study, we may have underestimated the association between the kyphosis angle and physical performance by selecting participants who were fit enough to undergo the DXA scans and the physical performance tests at the follow-up visit. We limited our analyses to the 1 220 participants of the cohort in whom a DXA was performed. The decision of whether a participant received a DXA scan was merely based on the availability of a DXA scanner in the study center. Yet, the DXA scan at the follow-up visit was only made if participants were able to visit the study center again. Data on physical performance at the follow-up visit were missing in 5%–10% of the participants. In one third to half of these cases, missing data was due to drop-out because of physical or cognitive decline or because the participant had deceased. The other cases were missing because of a missing DXA scan at the follow-up visit, or because the physical performance test was not recorded. Thus, the follow-up data may concern a healthier selection of the original cohort. However, we compared relevant baseline characteristics between the group with and the group who dropped out or had no physical performance tests at follow-up, and found no differences in age or comorbidities. Therefore, we have no reason to assume that due to selection we underestimated the association between the kyphosis angle and physical performance.

In conclusion, a larger kyphosis angle was independently associated with poorer physical performance both cross-sectionally and longitudinally. A larger kyphosis angle was associated with a decline of physical performance over time, only in women of the oldest quartile (aged 77 years and older). A larger kyphosis angle preceded a poorer physical performance, and the direction of this association was not reversed.

The kyphosis angle is potentially modifiable through early treatment of underlying osteoporosis and through training of posture and back extensor muscles (46). To the best of our knowledge, only in one intervention study, both reduction of the kyphosis angle immediately after a 3-month exercise and posture intervention, as well as prevention of progression of the kyphosis angle 3 years after intervention was reported (47,48). Participants (n = 103, mean age 70.0 ± 5.7 years, mean kyphosis angle 52.0° ± 7.4°) completed a twice-weekly group intervention during 3 months. Only 40% (n = 42) participated in the follow-up measurements, in which was shown that the kyphosis angle did not change (−1.5°, 95% CI −3.9°–1.0°). As the sample size was small, and selection bias possible, the results of this small cohort thus need to be interpreted with caution. Future studies should focus on investigating whether a larger kyphosis angle causes poorer physical performance. If a causal relationship between a larger kyphosis angle and poorer physical performance has been established, interventions reducing the kyphosis angle or prevent long-term progression of the kyphosis angle can be investigated. In the current study, a larger kyphosis angle was associated with both impaired balance and lower muscle strength. Therefore, along with reinforcing muscle strength, balance training should also be part of the intervention to counteract this loss. Early detection and effective treatment of hyperkyphosis may prevent further increase of the kyphosis angle, thereby preserving physical performance. Improvement of identification of risk factors for the decline of physical performance and interventions tailored to prevent further decline may enhance independence and quality of life of older adults.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

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Conflict of Interest

None declared.

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Study concept and design: M.C.K., H.C.W., and N.v.d.V. Acquisition of data: M.C.K., H.C.W., I.M.H., K.M.A.S., S.C.v.D., P.L., L.C.P.G.M.d.G., T.J.M.v.d.C., M.C.Z., N.M.v.S., and N.v.d.V. Analysis and interpretation of data: M.C.K., H.C.W., N.M.v.S., and N.v.d.V. Drafting of the manuscript: M.C.K., H.C.W., and N.v.d.V. Critical revision of the manuscript for important intellectual content: M.C.K., H.C.W., I.M.H., K.M.A.S., S.C.v.D., P.L., L.C.P.G.M.d.G., T.J.M.v.d.C., M.C.Z., N.M.v.S., N.v.d.V.

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