

ORIGINAL ARTICLE

Characteristics of postural control among young adults with asthmaNikita A. Kuznetsov, PhD^{1,2,3}, Christina M. Luberto, MA², Kimberly Avallone, PhD², Kristen Kraemer, MA², Alison C. McLeish, PhD², and Michael A. Riley, PhD^{2,3}¹Department of Biology, Northeastern University, Boston, MA, USA, ²Department of Psychology, University of Cincinnati, Cincinnati, OH, USA, and³Center for Cognition, Action, & Perception, University of Cincinnati, Cincinnati, OH, USA**Abstract**

Objective: We investigated whether young adults with asthma have impaired balance and whether this impairment is related to altered musculoskeletal function and/or psychological characteristics. **Methods:** 21 participants with a self-reported asthma diagnosis but no known postural instability or history of falls, and 18 control participants were recruited from undergraduate psychology courses. Participants performed a postural control task of maintaining the center of pressure (COP) in a fixed position with visual feedback (feedback condition) and while standing as still as possible without visual feedback (no-feedback condition). COP variability, regularity and task performance were used to characterize the quality of balance. To document group differences in musculoskeletal function, we measured neck and lower back angles as well as range of motion (ROM) of the neck in the frontal and sagittal planes. To document group differences in psychological state, we administered self-report questionnaires to assess symptoms of anxiety and depression, anxiety sensitivity and negative affect. **Results:** COP variability and task performance were similar between the groups, but participants with asthma exhibited more regular anterior–posterior COP dynamics. Participants with asthma had smaller ROM of neck extension, a more forwardly bent neck, greater thoracic spine angle, and they reported greater levels of the physical concerns facet of anxiety sensitivity. These musculoskeletal and affective variables moderated COP differences between the groups. **Conclusions:** Young adults with asthma showed a different postural control strategy in the absence of any obvious balance impairment. This change in strategy is related to musculoskeletal and affective characteristics of individuals with asthma.

Keywords

Anxiety sensitivity, center of pressure, musculoskeletal function, nonlinear analysis, postural control, sample entropy, visual feedback

History

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Introduction

Long-term persistent asthma can contribute to altered motor function [1]. Several recent studies have hypothesized that asthma may have adverse effects on postural control [2–4] – the dynamic process of maintaining upright body position during standing [5]. It is important to examine this issue in more detail, because postural control and the ability to maintain stable balance form the basis of most activities of daily living. Decrements in postural control can negatively impact the quality of life and potentially lead to an increased risk of injurious falls as a person ages.

Efficacy of postural control (or balance) frequently is operationally defined in terms of the magnitude of variability of the center of pressure (COP) during standing under a variety of conditions (e.g. eyes open vs. closed; sway-referenced vs. stable support) [6]. Cunha et al. [3] reported

that middle-aged adults with well-controlled asthma have a greater area of COP displacement and COP velocity in the anterior–posterior (AP) plane compared to an age-matched control group without asthma, especially in a more difficult condition of standing with eyes closed and on a sway-referenced platform. Results of another study showed that children and teenagers with asthma have greater overall amplitude of COP displacement when standing still with eyes open and that the effect is more pronounced when standing with eyes closed [4]. Those results suggest a decline in the quality or efficacy of postural control for individuals with asthma suggestive of a decrement in their balance.

Several explanations for these findings have been proposed. Long-term musculoskeletal alterations associated with asthma may be responsible for these changes in COP parameters [7]. According to this explanation, individuals with asthma routinely overuse accessory respiratory muscles (e.g. scalenes, sternocleidomastoids) in order to overcome increased airflow resistance. This leads to muscle shortening and a change in the static postural alignment of the neck and thoracic segments: a more forwardly bent neck angle, more forwardly positioned shoulders, decreased spine flexibility and decreased chest range of motion (ROM) have been

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reported [7,8]. If the static posture of an individual with asthma deviates excessively from the vertical, then that individual's postural variability may be increased because it would require more muscular activity to counteract increased gravitational torques at each of the postural joints [9].

Another possible reason for differences in COP characteristics is related to psychological factors [3] that are known to affect postural control [10,11]. Rates of psychopathology, particularly panic psychopathology (i.e. panic attacks, panic disorder and agoraphobia), are more common among individuals with asthma compared to the general population [12,13]. Thus, it is possible that differences in affective states more generally and in particular panic-related risk factors such as anxiety sensitivity (fear of arousal-related sensations) [14] contribute to changes in postural control dynamics among individuals with asthma.

While the contributions of musculoskeletal and affective factors have been mentioned as possible explanations for altered postural control dynamics in people with asthma [3], these proposals have not yet been directly empirically evaluated. Accordingly, the aims of the current study were to: (1) characterize the quality of postural control of young adults with asthma using measures of COP variability and regularity compared to young adults without asthma and (2) to evaluate the contribution of altered musculoskeletal function and psychological factors to any observed postural control differences between the groups. We predicted that COP position would show higher variability in the asthma group and that COP regularity (quantified by sample entropy [15]; described below) would be different between the groups. We also hypothesized that any observed increases in COP variability or changes in COP regularity would be related to musculoskeletal characteristics and/or affective state variables characterizing participants with asthma.

Methods

Participants

All participants for this cross-sectional study were recruited from the participant pool in the Department of Psychology at the University of Cincinnati for partial course credit and gave written informed consent. In order to qualify for the study, participants in the asthma group were required to have physician-diagnosed asthma and a current prescription for an asthma-related medication prior to participating in the experiment. This approach to selecting participants with asthma has been successfully used in previous work [16,17]. Further characteristics of the asthma sample are given in the "Results" section. All experimental procedures were approved by the University of Cincinnati Institutional Review Board. Participants in both groups were free from recent injuries to the arms or legs.

Measures

Assessment of musculoskeletal function

Static postural alignment. In order to capture the characteristics of postural alignment, the lumbar and neck angles were measured using an inclinometer. During the measurement, participants stood comfortably and fixated on a visual



Figure 1. Illustration of the static neck and lumbar angle measurement together with the utilized coordinate system.

reference point positioned 1 m away at eye level. To measure the neck angle, an inclinometer was placed over the spinous process of the C7 vertebra. Greater values reflected greater forward neck flexion. The measurement was repeated at the T12/L1 level to obtain lumbar inclination angles. Greater values (closer to 360°) reflected a more upright/straight lumbar region. Figure 1 provides an example of neck and lumbar spine angle measurements.

Neck Range of Motion. The ROM of neck flexion/extension and lateral neck extension on both sides were measured according to the procedures described in Norkin and White [18]. For all measurements described below, participants were seated in a chair with lumbar and thoracic spine support. All measurements started from a neutral head position (looking forward).

Flexion. The experimenter guided the head (one arm on the back of the head and one on the chin) to the chest until resistance to cervical flexion was felt. The distance between the chin and the sternal notch in this position was used as an index of maximal neck flexion with greater values indicating smaller ROM of neck flexion.

Extension. The experimenter guided the head upward and posteriorly until resistance to further motion was felt. The distance between the chin and the sternal notch in this position served as an index of maximal neck extension with greater values indicating greater neck extension ROM.

Lateral extension. The experimenter moved the head to the side toward the shoulder (one arm on the back of the head and another on the shoulder) until resistance to the motion was felt coming from the opposite shoulder. The distance between the mastoid process and the lateral tip of the acromial process (contralateral to the flexion side) was taken as a measure of the ROM of neck lateral extension with greater values indicating greater ROM. The same measurement was repeated for both shoulders.

Self-report measures

Anxiety Sensitivity Index-3 (ASI-3). The ASI-3 [19] is an 18-item measure that asks respondents to rate the degree to which they fear negative consequences of anxiety symptoms. The ASI-3 measures three facets of anxiety sensitivity: physical (e.g. “It scares me when my heart beats rapidly”), cognitive (e.g. “When I feel ‘spacey’ or spaced out, I worry that I may be mentally ill”) and social (e.g. “It is important not to appear nervous”). The ASI-3 has strong psychometric properties, including good internal consistency and convergent, and discriminant validity [19]. Internal consistency was good for the physical, cognitive and social concerns subscales in the current study (Cronbach’s $\alpha = 0.78, 0.86$, and 0.75 , respectively).

Positive affect negative affect schedule (PANAS). The PANAS is a mood measure commonly used in psychopathology research that indexes the broad-based disposition to experience negative (e.g. anxiety, anger) and positive (e.g. excited, proud) affective states [20]. Cronbach’s α in the current study was 0.85 for negative and 0.90 for positive affect.

Inventory of depression and anxiety symptoms (IDAS). The IDAS [21] is a 64-item self-report measure that assesses specific symptom dimensions of major depression and anxiety disorders. The IDAS contains 10 symptom scales (Suicidality, Lassitude, Insomnia, Appetite Loss, Appetite Gain, Ill Temper, Well-Being, Panic, Social Anxiety, and Traumatic Intrusions) and two broader scales (General Depression and Dysphoria). The IDAS shows strong convergent, discriminant, criterion, and incremental validity [22]. Cronbach’s α ranged from 0.70 to 0.96 in the current study.

Apparatus

A Bertec force plate (4060-NC; Bertec Corporation, Columbus, OH) was used to collect AP and medio-lateral (ML) COP data (COP_{AP} and COP_{ML} , respectively). The strain gauge signal was amplified (Bertec AM-6701) at gain 10 for each channel at 50 Hz using a 16-bit A/D board (Measurement Computing PCI-DAS 1200JR) controlled via Matlab’s Data Acquisition Toolbox (Mathworks, Natick, MA). The smallest discernible COP deviation was 0.01 cm.

In one condition, visual feedback was shown on a flat-panel screen (Samsung HL-S4676S, 101×56.5 cm; 1024×768 resolution). The display included a red dot (8 pixels; 0.7 cm) that tracked the values of the COP_{AP} and COP_{ML} . Participants were required to maintain the feedback dot at the center of a rectangular target (60×60 pixel; 5.5×4 cm) located at the center of the screen. The center of the target was marked by crosshairs formed by two intersecting lines that bisected the square vertically and horizontally. The display was positioned on a 90-cm tall table located 1.5 m from the participant. Movement of the feedback dot was related to the movement of the COP with a gain of 1 (i.e. a 1 cm ML displacement of the COP corresponded to a 1 cm or a 12 pixel displacement of the feedback dot; AP displacement was also 12 pixels or 0.6 cm). Placing more pressure on the left foot moved the feedback dot to the left and leaning forward the dot moved it upwards.

Procedure

The experiment started with the measurement of postural control. First, participants self-selected a standing position with the feet hip-width apart such that the pressure applied to both feet was perceived to be equal, and there was no self-perceived forward or backward lean while maintaining the feedback dot on the target. The experimenter then traced the outline of the feet to ensure stance reproducibility. The instruction for the feedback condition was to maintain the feedback dot at the center of the target as closely as possible. In the no-feedback condition, the instruction was to stand as still as possible while looking at the target square (i.e. quiet stance). Each trial lasted 120 s with breaks up to 60 s taken as needed. There were five repetitions of each condition for a total of 10 randomized-order trials per participant.

The participant groups were then characterized in terms of their musculoskeletal function and affective state in order to later determine if those participant variables related to any observed differences in postural control. A series of musculoskeletal alignment and ROM tests were administered by the experimenter who was trained in these procedures by a licensed physical therapist. We then administered self-report questionnaires assessing symptoms of anxiety and depression, anxiety sensitivity and negative affect.

Data analysis

COP variability

The standard deviation of COP_{AP} and COP_{ML} position and velocity were calculated to capture changes in the magnitude of COP variability. Velocity (v) time series were calculated at sample i according to $v_i = (x_{i-1} - x_{i+1})/2\Delta t$, where Δt is the sampling period and x is the COP position.

COP regularity measure

SampEn. The time-dependent structure of the COP was quantified using SampEn [15]. SampEn gauges the degree of regularity (predictability) of a signal. A highly periodic, predictable signal would yield a SampEn value close to 0 , while noisy and unpredictable signals have higher SampEn values. The analysis requires setting two parameters: the length of the template (m) and the size of the tolerance region (r) that defines a match between data values. A random 20% of the dataset was examined over the combinations of different values of m (from 1 to 5) and r [from 0.01 to 0.80 of the median absolute deviation (MAD) in increments of 0.03]. The MAD was used instead of the standard deviation to minimize the effect of outliers on the SampEn estimate. Based on this procedure, m was set at 2 for both position and velocity data, and r was set at 0.07 of the MAD for the position data, and 0.15 for the velocity data such that the standard error of the SampEn estimate was always less than 0.05 [23].¹

For the sample entropy (SampEn) analysis, the COP_{AP} and COP_{ML} data were band-pass filtered between 0.049 and

¹The SampEn software was downloaded from PhysioNet. The software inputs for the sampen.m function were $m = 3$ and $r = 0.07$ (0.15) of MAD.

5.26 Hz using an adaptive filter [24]. The high-frequency limit was chosen to minimize the effects of force platform measurement noise. The low-frequency limit was chosen to remove global trends in COP. Preliminary analysis showed that SampEn is sensitive to COP non-stationarity such that global trends decreased SampEn values even if the overall short-term characteristics of the COP remained similar. Such filtering focused on postural control mechanisms associated with intermediate balance corrections as opposed to global weight shifts on the time scale over 20.49 s (e.g. slight forward leaning). For COP variability analysis, only the low-pass filter with the 5.26-Hz cut-off frequency was used.

Statistical analysis

As a first step in the analysis, a linear mixed-effects model [25] was used to evaluate differences between the asthma and the control groups on the COP variability and SampEn measures. Trial, group (asthma vs. control), feedback (feedback vs. no feedback) and the group $\times$ feedback interaction were entered as fixed factors. The main effect of trial was included to examine the presence of any learning or fatigue effects. Participants were specified as a random factor with an autoregressive correlation structure for observations within each participant (random-intercept model). Sequential sums of squares were used to calculate the F values and the associated p values for each of the overall effects. The overall effects were considered statistically significant if the p value was lower than $\alpha = 0.05$. We used $\log_2$ -transformed data because the raw SampEn and COP variability values were positively skewed.

The second step in the analysis was to assess the contribution of the variables related to static postural alignment (neck and lumbar angles), neck ROM (forward and lateral extension) and affect (ASI-3, PANAS, IDAS) to any identified group differences in the COP variables. These variables were individually included as covariates to the original no-covariate model (described in the previous paragraph) if the latter exhibited a significant group effect or a group $\times$ feedback interaction in the first place. If the group difference was no longer statistically significant after including a covariate, then it was considered to be an explanatory variable for the original difference between the groups. The relative importance of a covariate was quantified as the difference between the unstandardized β -weights associated with the group effect prior to and after the addition of the covariate.

To decide which covariates to include, group differences based on all potential covariates were first examined and only those that were significantly different between the groups were used. The group differences were assessed using a mixed-effects model with group and gender as fixed factors (the two main effects and their interaction were included). Participants were defined as a random factor with a compound symmetry correlation structure.

In the following results section, group differences based on the covariate variables are reported first and then followed by the results of the COP variability and regularity measures in the postural control task with and without the adjustment for these covariates. All statistical analyses were carried out using the R package *nlme*.

Results

Asthma sample characteristics

21 young adults (mean $\pm$ SD; 19.87 ± 2.77 years; 6 men, 15 women) with a self-reported asthma diagnosis and 18 control participants (20.04 ± 1.85 years; 3 men, 15 women) without an asthma diagnosis took part in the study. The asthma control test (ACT) [26] scores for the asthma group ($M = 21.61$, $SD = 3.87$) indicated that the participants were in good control of their symptoms – only three had poorly controlled asthma (ACT < 20). Five participants were diagnosed when they were infants (birth to 1 year), four in early childhood (2–5 years), six in middle childhood (6–11 years), three in the early teenage years (12–14 years) and three in the late teens (15–17 years). When asked about symptoms in the last 2 weeks, 6 participants reported having no symptoms (but two of these subjects have been hospitalized for asthma symptoms within 2 years of the experiment and one within 8 years), 10 said that they had minimal symptoms, 3 had occasional symptoms and 2 stated that they had symptoms on most days. 10 reported at least one hospitalization due to asthma.

Static postural alignment

Neck angle

Neck angle was greater in the asthma group ($M = 33.83^\circ$, $SD = 4.55^\circ$; 95% CI [16.33° , 25.02°]) than the control group ($M = 27.25^\circ$, $SD = 8.28^\circ$; 95% CI [30.85° , 36.82°]), $F(1,34) = 9.15$, $p < 0.01$, indicating a more forward-flexed head position.² There was no main effect of gender and no gender $\times$ group interaction ($p > 0.05$).

Lumbar angle

Lumbar curvature was also greater in the asthma group ($M = 340.43^\circ$, $SD = 6.50^\circ$; 95% CI [337.94° , 342.93°]) than in the control group ($M = 344.68^\circ$, $SD = 4.10^\circ$; 95% CI [345.31° , 352.56°]), $F(1,34) = 7.17$, $p = 0.01$, indicating a greater backward bend of the thoracic spine. The main effect of gender and the gender $\times$ group interaction were not significant ($p > 0.05$).

Neck ROM

Neck flexion

Neck flexion ROM was not different between the groups (asthma: $M = 3.42$ cm, $SD = 0.96$ cm; control: $M = 3.63$ cm, $SD = 1.18$ cm), $F(1,35) = 0.34$, $p = 0.56$. The main effects of gender and the gender $\times$ group interaction were not significant ($p > 0.05$).

Neck extension

ROM of neck extension was smaller in the asthma group ($M = 19.90$ cm, $SD = 2.17$ cm; 95% CI [19.08 cm, 20.72 cm]) than the control group ($M = 21.03$ cm, $SD = 1.40$ cm; 95% CI [20.94 cm, 23.36 cm]), $F(1,35) = 4.32$, $p = 0.04$. There was no

²One participant in the asthma group did not have the neck and lumbar inclinometer measurements.

main effect of gender and no gender $\times$ group interaction ($p > 0.05$).

Neck lateral extension

The left and right lateral extension measurements were averaged because they showed a similar pattern of results. ROM of lateral neck extension was not different between the asthma ($M = 27.34$ cm, $SD = 2.90$ cm) and control groups ($M = 28.03$ cm, $SD = 2.18$ cm), $F(1,35) = 2.58$, $p = 0.12$. Women ($M = 26.86$ cm, $SD = 2.11$ cm) had smaller lateral extension values than men ($M = 30.30$ cm, $SD = 2.30$ cm), $F(1,35) = 17.93$, $p < 0.001$. There was no group $\times$ gender interaction ($p > 0.05$).

Questionnaire data

Out of all examined scales (IDAS, ASI-3, and PANAS), only the physical concerns subscale from the ASI-3 (AS-PC) revealed a significant group difference (asthma: $M = 5.42$, $SD = 4.03$; 95% CI [5.48, 10.34]; control: $M = 2.94$, $SD = 2.35$; 95% CI [1.16, 4.72]), $F(1,35) = 7.30$, $p = 0.01$. There were no significant group or gender main effects, as well as gender $\times$ group interactions for any other questionnaire measures (all $p > 0.05$). A $\log_2$ transformation was applied to the AS-PC scores because they were positively skewed.

Postural control characteristics

Performance in the visual feedback condition was quantified with the standard deviation of the COP about the center of the target according to the formula: Performance $SD = (\text{COP}_{AP} - \text{Target}_{AP})^2/N + (\text{COP}_{ML} - \text{Target}_{ML})^2/N$, where N is the total number of COP samples and Target_{AP} and Target_{ML} were located at (0,0). The analysis of task performance showed that there was no difference between the asthma ($M = 0.56$, $SD = 0.35$) and the control groups ($M = 0.45$, $SD = 0.14$), $F(1,35) = 2.62$, $p = 0.11$. There was no effect of trial on task performance.

COP_{AP} SampEn was lower in the asthma group ($M = 0.62$, $SD = 0.08$; 95% CI [0.56, 0.62]) than the control group ($M = 0.66$, $SD = 0.05$; 95% CI [0.63, 0.68]), $F(1,37) = 4.45$, $p = 0.04$. There was also a slight COP_{AP} SampEn increase in the feedback ($M = 0.64$, $SD = 0.06$) condition compared to the no-feedback condition ($M = 0.63$, $SD = 0.07$), $F(1,345) = 4.66$, $p = 0.03$. The effect of trial and the group $\times$ feedback interaction were not significant ($p > 0.05$). Figure 2 illustrates the visual characteristics of COP_{AP} time series for a range of SampEn values.

Table 1 shows the effects of the covariate adjustments to the group main effect for COP_{AP} SampEn. Lumbar angle during comfortable stance accounted for most of the original effects of asthma (48.94%), followed by the AS-PC (31.73%), and then by neck ROM (23.42%). Static neck angle did not have a strong explanatory effect on the original group difference.

The relations between COP_{AP} SampEn and the covariates were also examined. There was no relation with neck angle, $F(1,35) = 0.57$, $p = 0.45$; a positive relation with lumbar angle, $F(1,35) = 10.56$, $p = 0.003$; a positive relation with neck extension ROM, $F(1,36) = 4.34$, $p = 0.04$; and a negative relation with AS-PC, $F(1,36) = 6.35$, $p = 0.02$. AS-PC showed

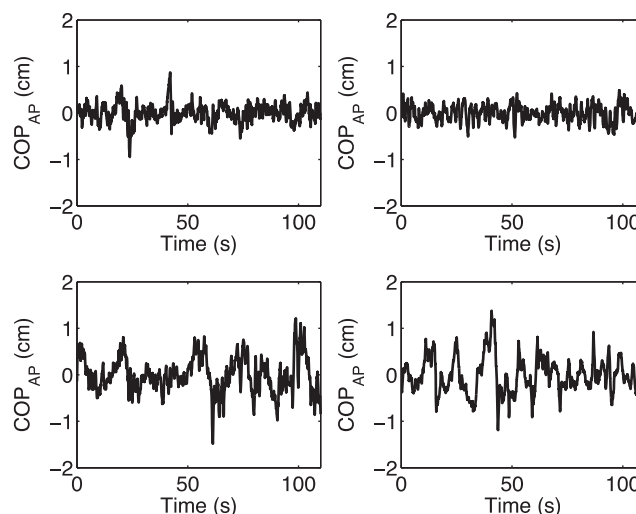


Figure 2. Illustration of the pattern of changes in SampEn for different COP_{AP} time series from different participants. SampEn values from top left to bottom right corner are: 0.82, 0.70, 0.59 and 0.50. COP_{AP} data were band-pass filtered between 0.049 and 5.26 Hz before calculating SampEn.

Table 1. Effects of covariate adjustment on the COP_{AP} SampEn differences between the asthma and the control group.

Covariate models	<i>F</i>	<i>p</i>	Change in β -weight	Change in β -weight (%)
Neck angle	3.84	0.06	0.0042	4.94
Lumbar angle	1.29	0.26	-0.0416	48.94
Neck ROM	2.46	0.13	-0.0199	23.42
AS-PC	1.98	0.17	-0.0270	31.73

The F and p values are for the group effect (asthma vs. control) according to the relevant covariate model. The change in the β -weight column shows the difference between the unstandardized β -weight of the group effect in the no-covariate model ($\beta = 0.0850$) and the β -weight in the covariate model. This change is also expressed as a percentage.

a significant group $\times$ covariate interaction, $F(1,36) = 7.07$, $p = 0.02$ —the negative relation between COP_{AP} SampEn and AS-PC held only for the asthma group, while the control group did not show changes in COP_{AP} SampEn with changes in AS-PC.

None of the other COP measures (COP_{AP} SD, COP_{ML} SD, COP_{AP} Velocity SD, COP_{ML} Velocity SD, COP_{ML} SampEn, COP_{AP} Velocity SampEn, and COP_{ML} Velocity SampEn) showed group main effects or a group $\times$ feedback interactions. These results are presented in Table 2.

Discussion

The principal result of the study was that postural control of young adults with asthma was characterized by more regular dynamics (lower COP_{AP} SampEn) compared to young adults without asthma, while no group differences were detected in the magnitude of COP variability. There were several musculoskeletal changes in the asthma group including smaller neck ROM in the sagittal plane, slight backward tilt of the thoracic spine and a more forwardly flexed neck angle. Participants with asthma also reported a greater fear of anxiety-related physical sensations (higher AS-PC) than the

Table 2. Results of sample entropy and variability analyses of the COP in the asthma and control group.

	Feedback		No Feedback		Effect
	Asthma	Control	Asthma	Control	
SampEn					
COP _{AP}	0.63 ± 0.07	0.66 ± 0.05	0.62 ± 0.08	0.65 ± 0.05	Group, Feedback
COP _{ML}	0.73 ± 0.13	0.73 ± 0.09	0.73 ± 0.14	0.72 ± 0.1	
COP _{AP} Vel	0.77 ± 0.06	0.78 ± 0.04	0.77 ± 0.06	0.78 ± 0.04	Feedback
COP _{ML} Vel	0.82 ± 0.09	0.80 ± 0.07	0.83 ± 0.1	0.81 ± 0.07	
Variability					
COP _{AP}	0.38 ± 0.16	0.33 ± 0.08	0.53 ± 0.26	0.45 ± 0.17	Feedback
COP _{ML}	0.18 ± 0.08	0.17 ± 0.06	0.25 ± 0.13	0.27 ± 0.13	Feedback
COP _{AP} Vel	0.76 ± 0.27	0.77 ± 0.2	0.74 ± 0.26	0.79 ± 0.29	
COP _{ML} Vel	0.39 ± 0.12	0.44 ± 0.14	0.38 ± 0.13	0.46 ± 0.22	

The values are listed as mean ± SD. *SampEn* is reported in arbitrary units. Variability of COP_{AP} and COP_{ML} is in cm; Velocity is in cm/s. All listed effects were statistically significant at 0.05 level, not listed effects were not significant.

control group, but did not differ in terms of any other measured psychological factors. The results of the covariate-adjustment procedure showed that the lumbar angle, neck ROM, and AS-PC individually accounted for the observed group difference in COP_{AP} SampEn, while the neck angle did not. Moreover, greater anxiety sensitivity to physical concerns was associated with more regular COP dynamics among individuals with asthma, but not among non-asthmatic controls.

Lower values of COP_{AP} SampEn in the absence of increased COP_{AP} variability or of a decreased level of task performance suggest that postural control is not functionally impaired in young adults with asthma contrary to a previous report [3]. Instead, participants with asthma apparently used a different postural control strategy to achieve the same level of performance. We interpret that it was the relatively long-term COP_{AP} dynamics (up to 0.049 Hz) that were different in participants with asthma as opposed to the short-term dynamics because only COP position but not velocity SampEn showed group difference. SampEn of COP velocity mainly captures the high-frequency aspects of postural control, while SampEn of COP position is sensitive to both low- and high-frequency dynamics. Thus, on a descriptive level, participants with asthma allowed their COP position to drift further and implemented stabilizing corrections less frequently than the control group. However, such adaptations may be effective only in the short term and over longer time could lead to discernable postural control deficits as reported for middle-aged adults with asthma [3]. We suggest that these changes in postural control strategy are related to both musculoskeletal (altered use of accessory respiratory muscles and change in the thoracic spine alignment) and psychological (greater fears of anxiety-related physical sensations) characteristics of individuals with asthma. Alternatively, our task may not have been challenging enough to reveal any postural control impairments as previous reports tended to show more pronounced effects in more difficult postural conditions [3,4].

Decreased neck extension ROM and the altered lumbar spine angle are consistent with the hypothesis that people with asthma habitually overuse the accessory respiratory muscles especially the scalenes [7]. The scalene muscles participate in elevating the upper section of the rib cage and also in forward neck flexions [27], and their shortening may have caused the

observed decrease in neck extension ROM [18]. However, there were no group differences with regard to lateral neck extension, indicating that the sternocleidomastoid muscles were not overused in this asthma sample. Participants in the asthma group also had a less vertically aligned posture (there was a slight backward tilt of the thoracic spine as indicated by a greater lumbar angle) than the control group. Such postural alteration would lead to less biomechanically efficient postural control because it would require more muscular effort since the body segments are less aligned with the gravitational vertical, increasing the torques required to resist rotational moments resulting from postural sway [9].

Consistent with the past research demonstrating the importance of the physical concerns facet of AS in asthma [16,28], AS-PC was the only psychological factor that significantly contributed to differences in postural control between individuals with and without asthma. A possible pathway for the influence of fear of arousal-related physical sensations on postural control is increased via attentional investment to controlling posture. Such internal monitoring and a decrease in postural control automaticity have been linked to increased COP regularity [29]. In general, individuals with high levels of anxiety sensitivity pay greater attention to somatic sensations [30] and have more accurate interoception [31] than people with low-anxiety sensitivity. Such increased awareness about bodily states may lead to less smooth inter-segmental postural coordination patterns resulting in a more reactive pattern of force injections to maintain stance as opposed to a more proactive, smooth control strategy that relies on multiple smaller corrections during more automatic stance. Moreover, attention toward bodily sensations might be further exaggerated among individuals with asthma, who regularly monitor physical sensations in order to determine appropriate asthma self-management strategies (e.g. when to take rescue medication), explaining the presence of correlation between AS-PC and AP COP regularity only in the asthma group.

Although these results are promising, there are a number of caveats that warrant consideration. First, the sample is relatively small, homogenous and non-randomly sampled. Most individuals with asthma reported well-controlled asthma; thus, there may be other group differences that are only evident among individuals with poorly controlled or

more severe asthma. Further studies are needed to explore these issues in larger, more diverse samples. Second, there was no objective verification of asthma diagnosis using spirometry or direct physician referral. In addition, these data are cross-sectional in nature. Longitudinal studies are needed to better understand how the associations between postural control, AS-PC and asthma change over time. Lastly, motor function in our sample of asthma patients could have been affected by standard drug therapy for asthma as beta-agonists are known to enhance tremor [32], but this possibility was not directly assessed in this study.

Despite these limitations, results of the current study indicate subtle but detectable changes in the spatio-temporal characteristics of postural control in young adults with asthma. These differences likely reflect the use of a different postural control strategy, as opposed to impaired postural control, per se, at least for young adults. Our results also suggest that increased COP_{AP} regularity among individuals with asthma is likely related to both musculoskeletal factors (reduced neck ROM and less vertically aligned posture) and fear of arousal-related physical sensations.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this paper.

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