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Activity of Erector Spinae During Trunk Forward Bending and Backward Return: The Effects of Age

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Abstract—Electromyography (EMG)-based measures of the trunk muscles behavior have been used for objective assessment of biomechanical impairments in patients with low back pain (LBP); yet the literature on normal age-related differences in such measures is scant. A cross-sectional study was designed to assess age-related differences in activity of trunk extensors during forward bending and backward return. Sixty asymptomatic individuals were recruited to form five gender-balanced age groups between 20 and 70 years old. Participants completed two sets of trunk forward bending and backward return task using self-selected and fast motion paces. For bending and return phases of each task, the normalized lumbar flexion angles corresponding to different event times of erector spinae activity along with the peak normalized and non-normalized EMG activities of erector spinae were calculated. The mean normalized and non-normalized EMG activities of erector spinae during the entire task also were calculated. There was no age-related difference in normalized lumbar flexion angles corresponding to different event times of erector spinae activity. However, the peak normalized EMG activity during forward bending and backward return as well as the mean normalized EMG activity during the entire task were found to be larger in older vs. younger individuals. Given the suggested unreliability of normalized EMG in elders and considering that we did not find any age-related differences in non-normalized EMG activity of erector spinae, our results do not strongly support the existence of normal age-related differences in EMG profile of erector spinae during forward bending and backward return. Therefore, when interpreting EMG-based measures of trunk muscles behavior for identification of biomechanical impairment in patients with LBP, potential abnormalities in EMG activity of trunk muscles may not be attributed to patient's age.

Keywords—Aging, Electromyography, Erector spinae, Trunk forward bending and backward return, Gender, Task pace.

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INTRODUCTION

Effective treatment of low back pain (LBP) requires objective assessments of lower back impairments in patients. Imaging data has been reported to be misleading and poorly related to LBP symptoms.[6,16,19,20,22] Assessment of lower back impairments via measures of physical performance is subjective and depends on motivational factors.[27,38] Electromyography (EMG)-based measures of the trunk muscles behavior have been suggested to be efficient for objective assessment of biomechanical impairments in patients' lower back.[10] For instance, EMG-based measures that characterize trunk flexion relaxation phenomenon (FRP) have been reported to clearly distinguish patients with LBP from healthy individuals.[10,43] In utilizing EMG-based measures for identification of biomechanical impairments in patients with LBP, it is important to consider the effects of several factors including recording and normalization techniques, lumbo-pelvic coordination, strength of trunk muscles,[10] pace of trunk motion,[31,36] loading condition,[31] lumbar flexibility,[14] and viscoelastic changes in the lower back tissues (e.g., creep deformation and stress relaxation)[29,35] on the timing and the magnitude of measured EMG activity. While many of these factors change with aging [1,11,18,33,34,37,42] and potentially affecting the characteristics of measured EMG activity of the trunk muscles, only a few studies have reported EMG activation profiles of the trunk extensors for older population during trunk forward bending and backward return movement; an activity that is used to characterize FRP.[21,26,28]

Kienbacher et al.[21] reported smaller value for the ratio of EMG activity of multifidi and semispinalis thoracic muscles in older vs. younger males, in older males vs. both younger and older females, and in older females vs. younger males. The ratio of EMG activity of a muscle in Kienbacher et al.[21] was defined as the magnitude of EMG activity of that muscle at 50% of full trunk forward bending divided by the magnitude of EMG activity of the same muscle at full trunk forward bending. Ng and Walter[28] found no differences in the normalized lumbar flexion angle at which FRP occurred between older and younger individuals. The reported ranges of lumbar flexion (20.7°) and thorax rotation (75.5°) in Ng and Walter[28] were, however, far below the reported values in the literature.[2] McGill et al.[26] reported larger normalized trunk muscles activity in older vs. younger individuals during trunk forward bending and backward return. However, they suggested that the older participants may have not exerted their true maximum effort during the required maximum voluntary contraction test, therefore normalization of EMG signals may have resulted in unrealistically larger values for older participants. In addition to offering inconclusive evidence, the above studies included either the elderly or two age groups of young (<40) and old (>65) individuals such that the age for initiation of change in measured EMG activity of trunk muscles during trunk forward bending and backward return was not clear. Given the reported significance of LBP in older population,[8,25,44,45] a better understanding of age-related differences in measured EMG activity of trunk muscles can enhance identification of biomechanical impairment in lower back using EMG-based measures particularly for older individuals.

EMG-based assessment of biomechanical impairments in patients with LBP first requires a knowledge of its normal distribution in asymptotic individuals. Given that the severity of LBP problem increases with age[7,17] and considering that current literature on muscle activation profiles in asymptomatic population has been mostly involved younger individuals,[30] the objective of this study was set to assess age-related differences in the measured EMG activity of the erector spinae in asymptomatic individuals. Differences in timing and magnitude aspects of EMG activity of erector spinae during trunk forward bending and backward return at self-selected and fast motion paces were investigated in individuals between 20 and 70 years old. Passive flexural stiffness of lower back has been reported to be larger in older vs. younger individuals,[11,33] hence suggesting a reduced demand for active contribution of the trunk extensors to spine equilibrium among older individuals. It has also been suggested that older individuals adopt a safer strategy (i.e., by increasing muscle activity) when performing trunk forward bending and backward return to increase the general balance and/or the actual spine stability and prevent back tissues injury.[26] Our recent findings also indicated that older vs. younger individuals implement a smaller lumbar flexion when performing trunk forward bending and backward return[34] which could be due to larger passive flexural stiffness of lower back and/or increased neuromuscular control. Therefore, on the basis of existing evidence no hypothesis was made on age-related differences in activity of erector spinae during forward bending and backward return and it was left to be the exploratory purpose of this study. However, considering the dynamic aspects of the motion,[4,5] it was hypothesized that the peak normalized EMG activity of erector spinae would be larger and would occur later/sooner during the forward bending/backward return phase of the fast vs. self-selected motion pace.

METHOD

Study Design and Participants

A cross-sectional study was designed wherein sixty asymptomatic individuals were recruited in five age groups (Table 1) and participated in the study after completing an informed consent procedure approved by the University of Kentucky Institutional Review Board. The age groups were gender-balanced and also were comparable on the basis of stature ($p = 0.851$), body mass ($p = 0.127$), and body mass index ($p = 0.139$) (Table 1). Our inclusion criteria were (1) absence of any musculoskeletal disorder, (2) a body mass index between 22 and 30, (3) being involved in occupations with minimal physical demand, and (4) no history of back pain during the past 12 month.[33,34,41]

Experimental Procedure

Each participant completed two identical data collection sessions that were separated by at least 48 h. These sessions were completed in the mornings to minimize occupational and diurnal effects on our outcome measures.[2] During each session, participants completed two sets of trunk forward bending and backward return task while instrumented with wireless Inertial Measurement Units (IMUs; Xsens Technologies, Enschede, Netherlands) and surface EMG electrodes (DE-2.1 Differential EMG sensor, Delsys, Natick, MA) for measuring trunk kinematics (sampling rate: 50 Hz) and activity of erector spinae (sampling rate: 1000 Hz), respectively (Fig. 1). The IMUs were attached on the trunk at the T10 and on the pelvis at the S1 spinous process. The EMG electrodes were attached bilaterally on erector spinae at the L3 and the L5 levels; located respectively 2 in. and 1 in. medio-

TABLE 1. Mean (SD) participant characteristics.

	Age (years)		Stature (m)		Body mass (kg)		Body Mass Index	
Age group	M	F	M	F	M	F	M	F
20–30	25.6(1.0)	23.5(2.3)	177.8(6.8)	164.9(3.7)	78.5(4.7)	61.4(6.4)	24.9(2.7)	22.5(1.6)
30–40	33.5(2.2)	34.0(1.2)	173.0(5.1)	167.4(7.1)	81.3(10.3)	64.5(10.2)	27.1(3.3)	22.9(2.5)
40–50	44.5(1.8)	45.1(1.4)	179.9(4.8)	166.2(5.4)	88.0(12.0)	70.1(12.1)	27.2(4.1)	25.3(3.8)
50–60	54.3(1.7)	56.0(2.3)	180.5(10.4)	163.4(6.0)	85.4(11.3)	72.0(8.7)	26.1(1.8)	26.3(3.1)
60–70	65.6(1.6)	65.0(2.7)	179.7(6.2)	163.5(5.7)	86.3(11.1)	61.0(4.1)	26.6(1.6)	22.8(1.2)

Each age group included six males and six females.

laterally on both sides of the midline of lower back.[12,23,24] For the first set of task, participants were instructed to stand in an upright posture (5 s), bend their trunk forward using a self-selected pace to reach their maximum comfortable trunk forward bending posture and hold that posture for 5 s, return back up to the initial upright position using the self-selected pace, and stand again in an upright posture for 5 s. For the second set of task, participants performed the same forward bending and backward return task but as fast as possible and without a wait period at the maximum trunk rotation. The task set with self-selected pace was performed prior to the set with fast pace and each set included three repetitions of the corresponding task. One minute break was given between these two sets of task. Prior to completion of these tasks, each participant completed two maximum voluntary trunk extension exertions, as described elsewhere,[41] to record maximum voluntary contraction (MVC) of erector spinae. There was a break of ~15 min between the MVC and the forward bending and backward return tasks. Raw EMG data were band-pass filtered (25–500 Hz), full-wave rectified and low-pass filtered using a dual-pass (fourth-order Butterworth filter) with a cut-off frequency of 2.5 Hz.

Data Analysis

For each instant of a given task, lumbar flexion angle was calculated as the difference between the measured thorax and pelvic rotations at the same time instant. Lumbar flexion angles for each repetition of a task were then normalized by dividing them by the maximum lumbar flexion angle recorded during that repetition. For each phase of the task (i.e., trunk forward bending and backward return), three normalized lumbar flexion angles were determined to represent specific event times in the recorded EMG of erector spinae (Fig. 2). These event times included (1) the onset time that corresponded to the onset of increase in EMG activity from a steady state level of activity (points *i* and *iv*); (2) the maximum time which denoted the time of maximum recorded EMG (points *ii* and *v*); (3) the cessation time which represented the terminal point of decrease in EMG (points *iii* and *vi*) before reaching the steady state level of activity (Fig. 2). Specifically, for a given phase of a task, the onset (cessation) time for each electrode was considered to be the time when the recorded EMG of that electrode became larger (smaller) than 5% of the maximum recorded EMG of the same electrode during both sets of task (happened to be the peak EMG during the backward return of the fast pace motion in most cases). Detection of the cessation event of EMG activity during the forward bending phase of self-selected pace task was considered as an indication for occurrence of FRP. We also calculated the FRP likelihood as the ratio of the number of times FRP occurrence was detected to the total number of task repetitions. Since there was no wait period at the maximum trunk rotation during task with fast motion pace, hence no period with steady state level of EMG activity, it was not possible to determine the timing of cessation of EMG activity during forwarding bending (point *iii*) and onset of EMG activity during backward return (point *iv*) (Fig. 2). Therefore, FRP likelihood was calculated using only values obtained from self-selected pace task (i.e., 6 repetitions over two sessions).

From normalized (i.e., normalized to MVC) and non-normalized EMG data, we also calculated the value of the maximum recorded EMG activity during both forward bending and backward return phases of each task. Additionally, the mean EMG activity for the whole duration of each task was also calculated.

Dependent Measures and Statistical Analysis

For each electrode and task set, the dependent measures included the normalized lumbar flexion angles corresponding to the onset, the maximum, and the cessation event times of recorded EMG activity; likelihood of FRP; the peak normalized and non-normalized EMG activity during forwarding bending and backward return phases; and the mean normalized and non-normalized EMG activity across the whole task. For each dependent measure, the values from the two

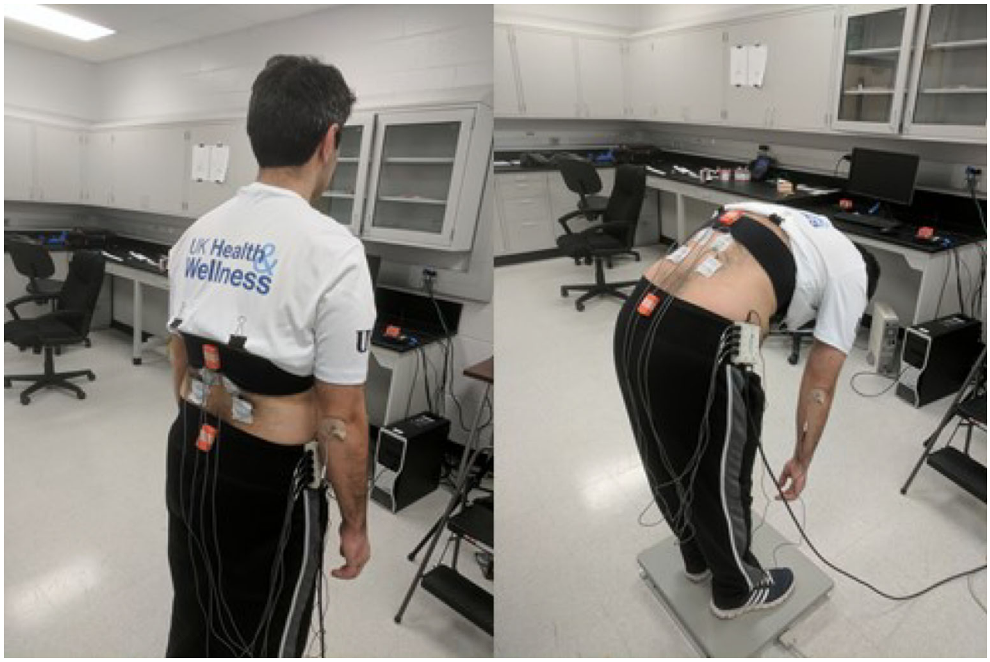

FIGURE 1. Measurement setup including wireless Inertial Measurement Units and surface EMG electrodes.

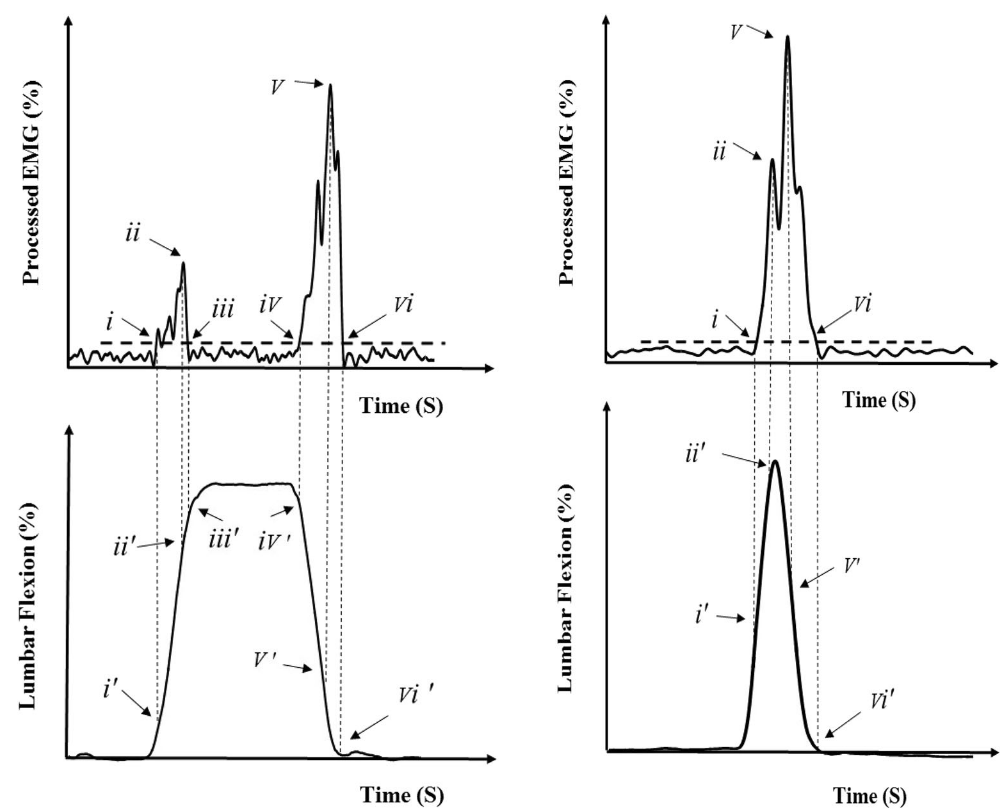

FIGURE 2. Normalized lumbar flexions (points *i'* to *vi'* in bottom row sub-figures) corresponding to the specific event times of the recorded EMG activity (forward bending: onset *i*, maximum *ii*, cessation *iii*; backward return: onset *iv*, maximum *v*, cessation *vi*). During task with fast pace (right), there was no wait period at the maximum trunk rotation, therefore, points *iii* and *iv* were not detected. The horizontal dashed lines in the top row sub-figures indicate the threshold of 5% of the maximum recorded EMG.

sessions, three repetitions (six trials), and four electrodes (i.e., total of 24 possible values for each dependent measure) were averaged for subsequent statistical analyses. For each dependent measure specific to the task with self-selected motion pace (i.e., the normalized lumbar flexion angle at the timing points *iii'*, *iv'*; and the likelihood of FRP), a univariate two-way ANOVA test, with age and gender as the independent variables, was used. For the remaining variables, mixed-factors ANOVA tests were used to assess the effects of age and gender, as between-subject variables, and motion pace, as the within subject variable, on the dependent measures. Significant ANOVAs were followed by post hoc analyses using Tukey's procedure. During the backward return phase of all tasks, all subjects kept the EMG activity above the steady state level until the last point wherein the normalized lumbar flexion angle reached zero, therefore the cessation event point *vi'* was zero for everyone and was removed from the statistical analyses. All statistical analyses were performed using SPSS (IBM SPSS Statistics 23.0, Armonk, NY, USA), and summary values are reported as means (SD). In all cases, a p value of 0.05 was considered as statistically significant.

RESULTS

Summary of statistical results is presented in Table 2.

Interaction Effects

There was a significant interaction effect of age*-gender on the normalized lumbar flexion angle corresponding to time of maximum EMG activity during backward return phase (i.e., at point *v'*; Table 2). Specifically, for individuals in the 50–60 (50 s) year-old age group, the maximum EMG activity during backward return occurred at larger normalized lumbar flexion angle ($F = 7.19$, $p = 0.021$) in male (52 ± 17%) vs. female (28 ± 12%) participants.

The interaction effect of age*pace on the normalized lumbar flexion angle denoting the time of maximum EMG activity during forward bending phase (i.e., at point *ii'*; Table 2) was significant such that for individuals in the 30–40 (30 s) and 50–60 (50 s) year-old age groups, the maximum EMG activity during forward bending phase occurred at larger normalized lumbar flexion angles (30 s: $F = 17.05$, $p = 0.002$; 50 s: $F = 17.35$, $p = 0.002$) under fast (mean ± SD for 30 s: 86 ± 10 and 50 s: 86 ± 13) vs. self-selected (mean ± SD for 30 s: 76 ± 15 and 50 s: 62 ± 16) motion paces.

The interaction effect of gender*pace on the peak non-normalized EMG activity during the backward return phase was also significant (Table 2). Specifically, in task set with fast pace, male participants (76 ± 21 μV) had larger peak non-normalized EMG activity ($F = 16.13$, $p < 0.001$) than females (52 ± 0.016 μV). Additionally, in male participants, the peak non-normalized EMG activity was larger ($F = 36.53$, $p < 0.001$) for fast (76 ± 21 μV) vs. self-selected (51 ± 17 μV) pace tasks. Finally, there was a significant effect of age*pace on the mean non-normalized EMG activity (Table 2) such that for individuals in the 40–50 (40 s) year-old age group, mean non-normalized EMG activity was smaller ($F = 6.27$, $p = 0.031$) in tasks with fast (mean ± SD: 13 ± 4 μV) vs. self-selected (mean ± SD: 18 ± 6 μV) pace.

Age-Related Differences

The peak normalized EMG activity during forward bending was larger in the 50–60 (50 s) than the 20–30

TABLE 2. Summary of statistical results for all outcome measures during trunk forward bending (FB) and backward return (BR).

		Age (A)		Gender (G)		Pace (P)		A × G		A × P		G × P		A × G × P	
		F	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Normalized lumbar flexion angle	*i'*	0.55	0.700	0.89	0.350	210.7	**<0.001**	1.27	0.294	0.76	0.558	1.90	0.174	1.20	0.323
	ii'	0.75	0.564	0.41	0.523	24.21	**<0.001**	0.52	0.723	3.24	**0.019**	0.50	0.483	1.04	0.394
	iii'	0.72	0.582	0.04	0.838	–	–	1.12	0.364	–	–	–	–	–	–
	iv'	0.75	0.565	0.89	0.352	–	–	0.80	0.532	–	–	–	–	–	–
	v'	0.26	0.903	0.13	0.715	1.71	0.197	3.11	**0.023**	2.50	0.054	0.21	0.649	0.89	0.475
Peak normalized EMG activity	FB	2.94	**0.045**	1.01	0.321	11.14	**0.002**	0.34	0.849	2.45	0.059	0.14	0.712	0.34	0.849
	BR	3.85	**0.008**	0.67	0.417	26.87	**<0.001**	0.55	0.698	1.25	0.302	1.10	0.300	0.40	0.807
Peak non-normalized EMG activity	FB	0.47	0.759	0.99	0.324	7.10	**0.011**	1.10	0.371	1.73	0.159	0.97	0.329	0.11	0.978
	BR	0.21	0.930	8.38	**0.006**	35.51	**<0.001**	1.33	0.275	0.86	0.495	11.45	**0.001**	0.57	0.689
Mean normalized EMG activity	–	3.30	**0.018**	2.64	0.111	0.81	0.374	0.19	0.943	2.00	0.109	0.21	0.646	0.94	0.449
Mean non-normalized EMG activity	–	0.63	0.642	0.02	0.894	3.84	0.056	1.83	0.139	3.14	**0.023**	0.94	0.337	0.89	0.476
FRP likelihood	–	0.35	0.843	2.00	0.163	–	–	2.09	0.096	–	–	–	–	–	–

Bold values indicate significant effect.

FRP flexion-relaxation phenomenon. The event times *i'* to *v'* were introduced in Fig. 2.

(20 s) year-old age group with the respective values of 53 ± 17 and 23 ± 10% (Tables 2, 3; Fig. 3). The same measure during backward return was larger in the two older groups (72 ± 28 and 77 ± 25%) than the two younger groups (41 ± 19 and 43 ± 24%) (Tables 2, 3; Fig. 3). Furthermore, the mean normalized activity over the entire task period was larger in the 60–70 (60 s) year-old age group (28 ± 7%) than the two younger groups (11 ± 5 and 12 ± 4%) (Tables 2, 3; Fig. 3). There was no age-related difference in other dependent variables (Tables 2, 3).

Gender Differences

The main effects of gender were not significant on any of the outcome measures (Table 2). Mean (SD) values of outcome measures for male and female participants are presented in Table 3.

Effects of Pace

The normalized lumbar flexion angle denoting EMG onset during forward bending phase (i.e., at point *i'*; Table 2) was larger in tasks with fast vs. self-selected motion pace (Table 3). Furthermore, the peak normalized EMG activity during forward bending and backward return as well as the peak non-normalized EMG activity during forward bending were larger in task with fast vs. self-selected motion paces (Tables 2, 3).

DISCUSSION

The main objective of this study was to investigate age-related differences in activity of erector spinae during forward bending and backward return in asymptomatic individuals. Only peak normalized EMG activity during forward bending and backward return as well as the mean normalized EMG activity during the entire task were found to be larger in older vs. younger individuals. The observed effects of pace (both main and interactive) on event times and magnitude of the recorded EMG activity supported our hypothesis that the peak normalized EMG activity would be larger and would occur later/sooner during the forward bending/backward return phase of tasks with fast vs. self-selected pace.

Our results on larger peak and mean normalized EMG activity of erector spinae in older vs. younger individuals were consistent with those reported by McGill et al.[26] However, as also suggested by McGill et al.,[26] older individuals may have not exerted their true maximum voluntary extension effort due to fear of injury or wisdom to conserve themselves. Our results on comparable normalized lumbar flexion at FRP between the age groups were also consistent with the reported similar FRP values between younger (20–25 years: 83.0%) and older (60–92 years: 84.0%) individuals.[28] Non-normalized EMG measures are preferred in clinical studies where subject groups are matched on the bases of factors like body mass, body mass index, and skin-fold thickness.[24,39] Since our age groups were comparable on the basis of height, body mass and body mass index (Table 1), we also analyzed non-normalized EMG activity of erector spinae. In contrast to measures obtained from normalized EMG activity, we did not find any age-related differences in peak and mean non-normalized EMG activity of erector spinae. Reports of larger passive stiffness of lower back in older individuals suggest a reduced demand for active contribution of the trunk extensors to spine equilibrium. Therefore, lack of difference in measured EMG activity of erector spinae between older and younger individuals in this study (instead of

TABLE 3. Mean (SD) of all outcome measures for different age groups, genders, and task paces during trunk forward bending (FB) and backward return (BR).

		Age group					Gender		Task pace	
		20–30	30–40	40–50	50–60	60–70	Male	Female	Self-selected	Fast
Normalized lumbar flexion angle (%)	*i'*	49 (13)	44 (10)	47 (11)	44 (14)	45 (12)	45 (11)	47 (13)	30 (12)	62 (15)
	ii'	81 (10)	81 (15)	81 (13)	75 (16)	76 (16)	80 (13)	78 (15)	74 (17)	84 (13)
	iii'	93 (5)	94 (4)	91 (6)	92 (4)	93 (4)	92 (4)	93 (5)	–	–
	iv'	91 (7)	86 (8)	83 (8)	92 (5)	91 (7)	91 (6)	87 (8)	–	–
	v'	38 (11)	39 (13)	35 (13)	40 (16)	37 (14)	38 (14)	38 (13)	36 (15)	40 (19)
Peak normalized EMG activity (%)	FB	23 (10)	30 (10)	33 (18)	53 (17)	46 (18)	34 (18)	41 (21)	33 (20)	42 (23)
	BR	41 (19)	43 (24)	58 (21)	72 (28)	77 (25)	54 (27)	62 (33)	49 (25)	67 (30)
Peak non-normalized EMG activity (μV)	FB	31 (15)	36 (11)	33 (17)	38 (17)	35 (14)	37 (17)	33 (16)	32 (13)	38 (18)
	BR	58 (21)	55 (19)	58 (27)	53 (25)	59 (20)	63 (23)	50 (19)	49 (19)	64 (24)
Mean normalized EMG activity (%)	–	11 (5)	12 (4)	16 (7)	22 (6)	28 (7)	15 (9)	21 (11)	18 (10)	18 (8)
Mean non-normalized EMG activity (μV)	–	14 (5)	14 (4)	18 (6)	16 (6)	17 (5)	15 (4)	15 (5)	16 (6)	15 (4)
FRP likelihood (%)	–	49 (21)	62 (18)	47 (23)	50 (26)	45 (24)	58 (25)	43 (19)	–	–

FRP flexion-relaxation phenomenon. The event times *i'* to *v'* were introduced in Fig. 2.

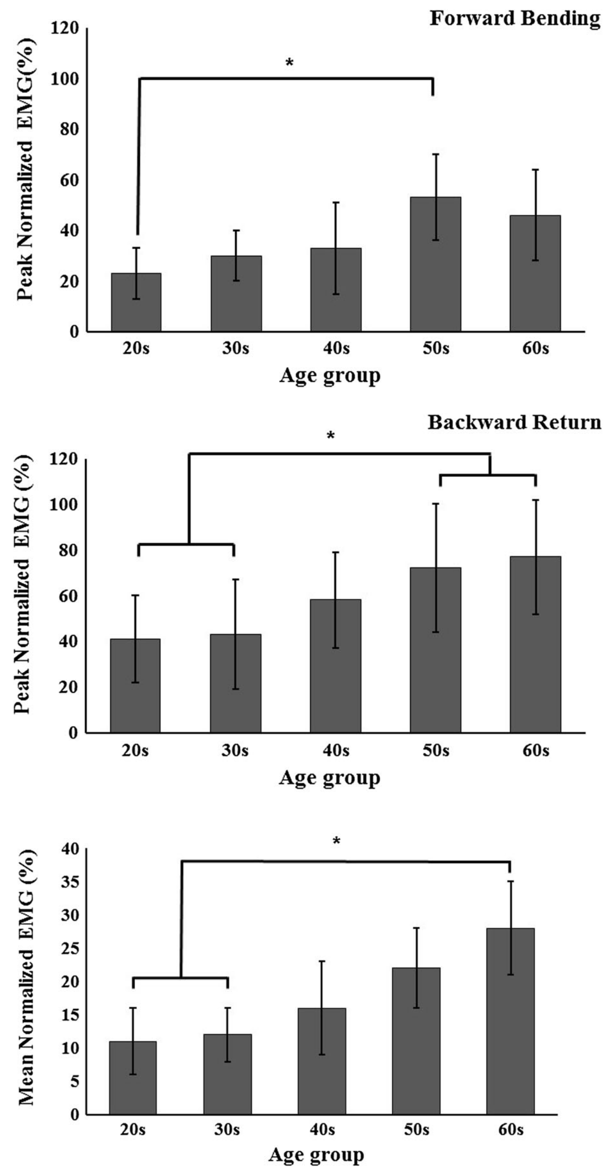

FIGURE 3. Age-related differences in peak normalized EMG during forward bending (top) and backward return (middle) as well as differences in mean normalized EMG during the whole task (bottom). The symbol * indicates significant paired differences and error bars indicate standard deviations.

a decrease with aging in response to increase in passive stiffness) may be considered as an increased neuromuscular control in older individuals.

We did not find any age-related differences in lumbar flexion angle at FRP (mean: 92.5%). Reported values of lumbar flexion at which FRP occurs range from ~70 to 100% of maximum lumbar flexion angle. Such divergent reports for lumbar flexion angle at FRP may be in part due to dependency of FRP on several factors.[10,14,15,29,31,35,36] The normalized lumbar flexion at FRP in our study was, however, consistent with reported values (80–91%) in studies[9,13,31,35,36] that had experimental procedures (forward bending task taking ~2 to 5 s and with no constraint on pelvis motion) comparable to our study (forward bending phase of the task with self-selected pace takes ~3 s). Our findings related to the normalized lumbar flexion at the onset of increase in EMG activity during backward return (i.e., 91%) also were consistent with earlier reported values (i.e., 88–97%) in studies with comparable experimental procedure.[9,13,31,35]

Male participants had larger peak non-normalized EMG activity than females in the task set with fast pace during the backward return phase. This is likely due to the larger body weight and height in male vs. female participants (Table 1), requiring higher EMG activity of trunk extensors to accelerate the motion and generate the required inertial forces. The moment demand of a given task on the lower back depends, among others, on the trunk flexion angle. Occurrence of the maximum EMG activity at larger normalized lumbar flexion angle in male vs. female participants of the 50–60 year-old age group can be explained by referring to our earlier reports[40] related to the larger lumbar contribution to trunk flexion in male vs. female participants particularly those in the above noted age group. In that study, we did not find any age and gender-related differences in trunk range of flexion, suggesting similar role of trunk flexion in demand of task on the lower back between ages and genders. However, for any given trunk flexion, lumbar contribution was larger in male vs. female particularly in the 50–60 year-old age group. Therefore, trunk flexion angles corresponding to the maximum task demand on the lower back, while were comparable between genders, were associated with larger lumbar flexion in males.[40] Finally, consistent with the study by Solomonow et al.,[35] we did not find any gender-related differences in the normalized lumbar flexion angle at FRP.

Task pace affects event times of the EMG activity and kinesiologic data.[31,32,36] Larger normalized lumbar flexion at the onset and at the time of maximum EMG as well as larger peak normalized/non-normalized EMG activity in fast vs. self-selected pace in our study are consistent with the required larger mechanical demand to generate and control fast vs. self-selected task paces. For instance, in the fast pace task, a delay in the onset and time of maximum EMG during forward bending allows the gravity and abdominal muscles to generate larger acceleration in early stage of forward bending while a larger peak EMG activity and the delayed appearance of FRP (as reported by Sarti et al.[31]) is required to overcome the large generated inertial forces and control the motion to avoid injury toward the ending stage of forward bending. Trendwise, the effects of pace on our results were, in general, consistent with prior studies.[31,36] The differences in the absolute values between our results and those of other studies come probably from differences in experimental procedures (e.g., task pace and subjects' characteristics among others) as well as data analyses (e.g., EMG signals processing, criteria for onset and cessation of EMG activity). For instance during the forward bending phase, we found larger normalized lumbar flexion at the event time of maximum EMG in tasks with fast (84%) vs. self-selected (74%) pace. For the same measure, however, Sarti et al.[31] did not find the increase in lumbar flexion angle from slow (69%) to fast (76%) pace to be statistically significant. This difference in results could be in part due to differences in paces of fast (i.e., 1 s in this study and 3 s in Sarti et al.[31]) and slow/self-selected (i.e., 3 s in this study and 8 s in Sarti et al.[31]) tasks between the two studies. Interestingly, when comparing task with similar pace (i.e., self-selected pace in our study vs. fast pace in Sarti et al.[31]), the results of normalized lumbar flexion at the event time of maximum EMG are very similar (74 vs. 76%).

Our study had some limitations that should be acknowledged. First, to enhance our ability to find age-related differences in the measured EMG activity of the erector spinae and draw robust hypothesis and conclusions, rather restrictive inclusion/exclusion criteria were used. Such criteria, however, weaken the generalizability of the results. Second, during the task with fast pace, participants were instructed not to pause at the maximum flexed posture to be able to generate a motion with as fast as possible pace. Our rationale for such experimental design was to maximize the pace and hence increase our ability to find pace-related differences in our outcome measures. However, such a design limited our ability to detect lumbar flexion angle at FRP as well as at the onset of EMG activity during backward return for task with fast pace. Third, the order of tasks was not randomized in our study to avoid the influence of task repetition on the trunk ranges of motion under self-selected pace. We used the trunk range of motion under self-selected pace to guide other subsequently completed tasks (not reported in this study) during each session.[33,41] Therefore in interpretation of our pace-related results, the order effects should be kept in mind. Finally, surface EMG electrodes do not provide information about the activity of deep trunk muscles. Andersson et al.[3] used fine wire electrodes to measure EMG activity of both superficial and deep trunk muscles (i.e., erector spinae and quadratus lumborum). While they observed FRP in the superficial erector spinae, EMG activity of deep erector spinae and quadratus lumborum persisted during the full flexion.[3] Age-related differences in activity of deep trunk muscles, however, remain to be investigated in future.

In conclusion, we did not find solid evidence for age-related differences in EMG activation profiles of the erector spinae during trunk forward bending and backward return tasks. This suggests that the EMG-based clinical database might be used for identification of biomechanical impairment in patients with LBP regardless of their age. In interpretation of such measures, however, the effects of task pace should be considered.

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