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ARTICLE

Posture in College Students: a quantitative analysis of body alignment, muscle fitness and mobility

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Abstract

Background: Most college students have alignment deficits and yet there is little information in the physical education curriculum about the nature of these deficits, or guidance on how students can overcome them. **Purpose**: The purpose of this study is to establish norms for common alignment deficits and to investigate the relationship between body alignment and physical fitness. **Methods**: 502 students conducted a posture lab during regular class-time; they observed their alignment in the frontal, sagittal and transverse planes and performed standard tests of muscle fitness and mobility. **Results**: Only 18 students had neutral body alignment. These students had higher scores on the plank, push-up and air squat tests. These results suggest a positive relationship between neutral alignment and muscle fitness. Other results identified relationships between specific alignment deficits with lower scores on muscle fitness and mobility tests. Rates of common alignment deficits were established as were population differences by sex, age and BMI. Students in the underweight BMI category had more alignment deficits compared to other students as did females compared to males. **Conclusion:** Posture is a valuable component of the physical education curriculum. Teaching fitness from a body alignment perspective can help students to overcome/reduce the effects of alignment deficits and improve athletic performance. **Health & Fitness Journal of Canada 2021;14(2):18-36.**
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Introduction

This study investigates the rate of alignment deficits among college students, and examines the relationships between alignment deficits, muscle fitness and mobility.

An alignment deficit occurs when two body segments join inefficiently instigating joint strain and excess muscle tension. A deficit is identified either by the joint or the displacement; for example, ankle pronation or forward head. Each deficit can affect adjoining body segments, instigating a chain reaction that can destabilize posture and reduce mobility (Gokhale, 2008; Starrett, 2013).

Posture assessment labs are common in college-level physical education; these labs are included in the following texts (Fahey, Insel, Roth & Wong, 2017; Hopson, Donatelle, & Littrell, 2013; Powers, Dodd & Jackson, 2017; Chevalier, 2016).

Unlike fitness assessments, alignment assessments do not provide population rates, or data on variance according to age, sex, or body mass index (BMI), and, other than the Chevalier 2016 text, most do not emphasize the beneficial relationship between body alignment and fitness. Without this information, students lack both a framework from which to analyze their results and have little guidance on how to make improvements.

The percentage of students with one or more deficits is expected to be high. According to Bricot (2008), 90% of the population have alignment faults. This is not surprising given the numerous factors that affect alignment; everything from genetics to culture (Gokhale, 2008). This study focuses on the effects of muscle weakness and muscle imbalance on alignment. The theoretical framework linking muscle development to alignment is well established (Page, Frank & Lardner, 1967). However, there is little applied research connecting alignment to fitness performance. The hypothesis of the study is that college students with ideal, neutral body alignment will have better results on muscle fitness and mobility tests when compared to students with alignment deficits.

Methods

In developing the assessment for this study, a survey of posture appraisals was conducted from many disciplines: the early work of Feldenkrais (1972); the rehabilitative approach of Vladimir Janda (Page, et. al., 1967); posture analysis for musicians (Mark, 2003), fitness training for elite athletes (Cook, 2003; Starrett, 2013; & Rippetoe, 2017); and from posture specialists (Gokhale, 2008; Bricot, 2008; & Kendall, McCreary, Provance, Rodgers & Romani, 2005;). Based on this literature, the following conception of posture and alignment were adopted for this study. Posture is considered to be a global concept that includes alignment, muscle development, joint mobility and body weight. Neutral body alignment is defined as having no deficits in the sagittal, frontal and transverse planes.

A new posture assessment was designed for this study (Figure 1). The tests in the sagittal and frontal planes are based on standard tests (Fahey et al., 2017). Given the importance that Gokhale (2008) places on pelvic alignment, a test of pelvic tilt was added. The 'the hands-on belly test' was developed to assess pelvic tilt and eliminate false swayback - individuals with large buttocks can sometimes appear to have swayback when they have, in fact, a neutral pelvic tilt. Assessments for rotation in the transverse plane are from Bricot (2008). The terminology of the assessment, including substitution of the term 'normal' with 'neutral', is adopted from Starrett (2013). The assessment is not graded, as it is in some texts. New graphics were designed by Nic DiLauro (Figure 1).

The fitness tests of general muscle strength included standard push-ups, air squats and planks. The hand dynamometer was used to test grip strength, and the one-foot, closed-eye test was used for balance. Mobility tests included the standing toe-touch, the lying hip flexion test and the superman test for shoulder mobility. For grip strength, balance, and hip mobility, participants noted separate scores for dominant and non-dominant sides. The Apley scratch test was used to test for shoulder mobility in relation to hand dominance.

Participants

Physical education is compulsory in Quebec colleges. This ensured a diverse population for the study. A total of 502 students participated from 29 various activity classes. The selection of classes was random; it depended on the schedule of the 10 teachers who volunteered their class time. There were slight variations in the total number of students for each test due to: late arrivals (about 1-3), students with injuries: push-ups (9) and air squats (8).

Student participation was anonymous and voluntary. Participant characteristics were obtained for sex and age, and participants entered their height and weight to calculate body mass index (BMI). All participants provided written informed consent. Ethical approval was obtained from the Dawson College Research Ethics Board. The study adhered to the guidelines established by the Declaration of Helsinki.

Experimental Design

The study was conducted during students' regular physical education class. There were 18-24 participants for each class. The assessment was projected on a screen in the sport facility. The students were guided through the assessment with the same instructions, stated only by the researcher, while the regular teacher circulated among the students to assist with quality control. All teachers were experienced with fitness testing and familiar with alignment assessment. For each alignment assessment, students entered their category—neutral or deficit—via their cell phones through a web link to a Microsoft Office form. Similarly, for the fitness assessment, students entered their numeric scores for tests of muscle fitness and their categories for tests of mobility. The Microsoft Office form generated the data sheet.

Data Analysis

The data analysis was carried out by the Adaptech Research Network in Montreal. The data is presented in 3 groups:

A: Rates of alignment deficits and population variance according to age, sex, and BMI, by percentage.

B: Fitness results and according to age, sex, and BMI. Additionally, results are presented for variance according to dominant vs. non-dominant side.

C: Analysis of fitness results by alignment: students with neutral alignment vs. students with no alignment deficits. ANOVA analysis was used to test for possible relationships between body alignment categories vs. numeric fitness scores. Chi Square analysis was used to test for possible relationships between body alignment categories and mobility categories.

Limitations of the Study

The data for the alignment assessment was based on participant self-observation, not measurement, and the data for the fitness assessment depended on participant adherence to performance criteria.

Results

Group A: Tables for Rates of Alignment Deficits & Variance by age, sex, and BMI. The alignment results include: rates of alignment (Table 1); population description by age, sex, and BMI (Table 2) and variance in rates of alignment deficits by age, sex, and BMI (Tables 3, 4, and 5).

Group B - Fitness Results

The fitness results include: muscle fitness results by age, sex, and BMI (Tables 6 & 7); mobility results by age, sex, and BMI (Tables 9 & 10) and fitness results by dominant vs. non-dominant side (Table 10).

Table 1: Rates of Alignment Deficits.

Sagittal Plane	n.	%
Lumbar Curve		
Neutral	373	75%
Swayback	94	19%
Flatback	33	7%
Pelvic tilt		
Neutral	380	76%
Anterior	86	19%
Posterior	33	7%
Head		
Neutral	266	53%
Forward	233	47%
Shoulders		
Neutral	314	63%
Forward	185	37%
Elbow		
Neutral	379	76%
Hyperextend	121	24%
Knees		
Neutral	333	67%
Hyperextend	166	33%

Frontal Plane	n.	%
Head		
Neutral	390	78%
Tilted	109	22%
Shoulders		
Neutral	218	44%
Higher on D.	150	30%
Higher on N-D	131	26%
Hips		
Neutral	372	75%
Tilted	127	25%
Knees		
Neutral	358	72%
Varus	42	8%
Valgus	99	20%
Ankles		
Neutral	310	62%
Supinate	41	8%
Pronate	148	30%
Foot Arches		
Neutral	243	49%
High	44	8%
Low	213	43%

Transverse Plane	n.	%
Shoulders		
Neutral	277	55%
Rot. to D	145	29%
Rot. to N-D.	78	16%
Back		
Neutral	360	72%
Rotated	140	28%
Pelvic Girdle		
Neutral	265	53%
Rot. to D.	138	28%
Rot. to N.D.	95	19%
Overall Alignment		
Neutral for all	18	4%
1 + deficits	481	96%

Table 2: Population Description by Sex, Age, & BMI for Participants with Neutral Alignment vs. Participants with Alignment Deficits.

Sex

	Males		Females		Prefer not to say		
	n	%	n	%	n	%	**Total**
Deficits	150	32%*	329	68%*	3	0%	482
Neutral	8	44%*	10	56%*	0	0%	18

Age

	17 - 21		22 -35		
	n	%	n	%	**Total**
Deficits	443	92%	41	8%	484
Neutral	16	89%	2	11%	18

BMI

	Underweight BMI < 18.5		Normal BMI 18.5-24.9		Overweight BMI 25-29.9		Obese BMI 30 +		
	n	%	n	%	n	%	n	%	**Total**
Deficits	52	10%*	300	63%*	94	20%	30	6%	476
Neutral	0	0%*	14	78%*	3	17%	1	5%	18

Note: the sex group ‘prefer not to say’ with 3 participants was too small to form a category for analysis. Thus, for all BMI charts, the maximum total number was reduced from 502 to 499.

Table 3: Variance in Rates of Alignment Deficits by Age.
(Age group 1: 17-21; group 2: 22-35) (level of significance* ≥ 5%, sample size≥ 10)

Sagittal Plane

Forward Head

Age	Neutral		Forward		**Total**
1	238	52%	219	48%*	457
2	28	67%	14	33%*	42

Knee Hyperextension

Age	Neutral		Hyperextension		**Total**
1	298	65%	159	35%*	457
2	35	83%	7	17%*	42

Forward Shoulders

Age	Neutral.		Forward.		**Total**
1	285	62%	172	38%*	457
2	29	69%	13	31%*	42

Elbow Hyperextension

Age	Neutral.		Hyperextension		**Total**
1	345	75%	113	25%*	458
2	31	81%	8	19%*	42

Lumbar Curve - no significance

Age	Neutral.		Swayback.		Flatback.		**Total**
1	340	74%	86	19%	31	7%	457
2	32	77%	8	19%	2	5%	42

Pelvic Tilt

Age	Neutral.		Anterior.		Posterior.		**Total**
1	343	75%	82	18%*	32	7%	457
2	29	69%	13	31%*	1	2%	42

Frontal Plane

Head - no significance

Age	Level.		Tilted.		**Total**
1	335	78%	102	22%	457
2	35	83%	7	17%	42

Shoulders

Age	Neutral.		Tilted		**Total**
1	196	43%	161	57%*	457
2	22	52%	20	47%*	42

Knees

Age	Neutral		Varus		Valgus		**Total**
1	325	71%	38	8%	94	21%*	457
2	33	79%	4	10%	5	12%*	42

Hips

Age	Neutral		Tilted		**Total**
1	336	74%	121	26%*	457
2	36	86%	6	14%*	42

Ankles

Age	Neutral		Supinate		Pronate		**Total**
1	279	61%	38	8%	140	31%*	457
2	31	74%	3	7%	8	19%*	42

Foot Arches - no significance

Age	Neutral		High Arch		Low Arch		**Total**
1	218	48%	44	10%	196	43%	458
2	25	60%	0	0%	17	40%	42

Transverse Plane

Shoulder Girdle Rotation

Age	Neutral		Rotated		**Total**
1	249	54%	209	46%*	458
2	28	67%	14	34%*	42

Pelvic Girdle Rotation - no significance

Age	Neutral		Rotation		**Total**
1	239	52%	217	48%*	456
2	26	62%	16	39%*	42

Back Rotation - no significance

Age	Neutral		Rotation		**Total**
1	334	72%	124	27%	458
2	29	69%	13	31%	42

Table 4: Variance in Rates of Alignment Deficits by Sex.
(level of significance* ≥ 5%, sample size ≥ 10)

Sagittal Plane														
M/F	Forward Head							Knee Hyperextension						
	Neutral		Forward		**Total**			Neutral		Hyperextension		**Total**		
M	76	49%	80	51%*	156			119	76%	37	24%*	156		
F	188	55	152	45%*	340			212	62%	128	38%*	340		
	Forward Shoulders - no significance							Elbow Hyperextension						
	Neutral.		Forward.		**Total**			Neutral.		Hyperextension		**Total**		
M	99	63%	58	37%	157			135	86%	22	14%*	157		
F	214	63%	125	37%	339			241	71%	99	29%*	340		
	Lumbar Curve							Pelvic Tilt						
	Neutral.		Swayback.		Flatback.		**Total**	Neutral.		Anterior.		Posterior.		**Total**
M	108	69%	33	21%	15	10%*	157	116	74%	23	15%	18	11%*	157
F	263	77%	60	18%	18	5%*	341	262	77%	62	18%	15	5%*	339
Frontal Plane														
	Head - no significance							Shoulders						
	Level.		Tilted.		**Total**			Neutral		Tilted.		**Total**		
M	122	78%	35	22%	157			80	51%	76	49%*	156		
F	265	78%	74	22%	339			136	40%	204	60%*	340		
	Knees							Hips - no significance						
	Neutral		Varus		Valgus		**Total**	Neutral		Tilted		**Total**		
M	117	75%	14	9%	25	16%*	156	114	73%	42	27%	156		
F	238	70%	28	8%	74	22%*	340	256	75%	84	25%	340		
	Ankles							Foot Arches						
	Neutral		Supinate		Pronate		**Total**	Neutral		High Arch		Low Arch		**Total**
M	107	69%	14	9%	35	22%*	156	85	54%	10	14%	62	39%*	157
F	201	59%	26	8%	113	33%*	42	156	46%	34	10%	150	44%*	340
Transverse Plane														
	Shoulder Girdle Rotation - no significance							Pelvic Girdle Rotation - no significance						
	Neutral		Rot. Dom.		**Total**			Neutral		Rotation		**Total**		
M	88	56%	69	44%	157			84	54%	72	46%	156		
F	187	55%	152	45%	339			180	53%	159	47%	339		
	Back Rotation													
	Neutral		Rotation		**Total**									
M	122	78%	35	22%*	157									
F	236	69%	104	31%*	340									

Table 5: Variance in Alignment Deficits by BMI.
(level of significance* ≥ 5%, sample size ≥ 10) U = underweight (<18.5); N = normal (18.5-24.9); O = overweight (25-29.9); Ob = obese 30+

Sagittal Plane

Forward Head

BMI	Neutral		Forward		**Total**
U	28	54%	24	46%	52
N	174	55%	140	45%*	314
O	45	46%	52	54%*	97
Ob	16	52%	15	48%	31

Knee Hyperextension

BMI	Neutral		Hyperextension		**Total**
U	35	67%	17	33%	52
N	214	68%	101	32%*	315
O	62	65%	34	35%	96
Ob	19	61%.	12.	39%*	31

Forward Shoulders

BMI	Neutral.		Forward.		**Total**
U	28	54%	24	46%*	52
N	202	64%	112	36%*	314
O	59	61%	38	39%	97
Ob	23	74%	8	26%	31

Elbow Hyperextension

BMI	Neutral.	Hyperextension			**Total**
U	36	69%	16	31%*	52
N	237	75%	78	25%*	315
O	62	65%	34	35%*	96
Ob	19	61%	12	39%*	31

Lumbar Curve

BMI	Neutral.		Swayback.		Flatback.		**Total**
U	38	74%	10	20%	3	6%	51
N	243	77%	53	17%*	20	6%	316
O	67	69%	23	24%*	7	7%	97
Ob	22	71%	7	23%	2	6%	31

Pelvic Tilt

BMI	Neutral.		Anterior.		Posterior.		**Total**
U	37	71%	13	25%*	2	4%	52
N	252	80%	44	14%*	18	6%	314
O	66	68%	22	23%*	9	9%	97
Ob	22	71%	6	19%	3	10%	31

Frontal Plane

Head - no significance

BMI	Neutral		Tilted.		**Total**
U	44	85%	8	15%	52
N	241	77%	73	23%	314
O	72	74%	25	26%	97
Ob	28	90%	3	10%	31

Shoulders

BMI	Neutral		Tilted.		**Total**
U	25	48%	27	52%	52
N	139	44%	176	56%*	314
O	36	37%	97	63%*	97
Ob	15	48%	16	52%	31

Knees

BMI	Neutral		Varus		Valgus		**Total**
U	38	73%	7	13%	7	13%	52
N	232	74%	21	7%	61	19%*	314
O	64	66%	10	10%	23	24%*	97
Ob	21	68%	3	10%	7	22%	31

Hips

BMI	Neutral		Tilted		**Total**
U	33	63%	19	37%*	52
N	239	76%	75	24%*	314
O	75	77%	22	23%	97
Ob	23	74%	8	26%	31

Ankles - no significance

BMI	Neutral		Supinate		Pronate		**Total**
U	30	58%	4	8%	18	34%	52
N	191	61%	27	9%	96	30%	314
O	60	62%	10	10%	27	28%	97
Ob	25	81%	0	0%	6	19%	31

Foot Arches - no significance

BMI	Neutral		High Arch		Low Arch		**Total**
U	23	44%	7	14%	22	42%	52
N	156	50%	24	8%	135	42%	315
O	44	46%	11	11%	42	43%	97
Ob	17	55%	1	3%	13	42%	31

Transverse Plane

Shoulder Girdle Rotation - no significance

BMI	Neutral		Rotation		**Total**
U	30	58%	22	42%	52
N	176	56%	139	44%	315
O	51	53%	46	47%	97
Ob	18	58%	13	42%	31

Pelvic Girdle Rotation

BMI	Neutral		Rotation		**Total**
U	31	59%	22	42%	52
N	171	55%	142	45%*	313
O	46	47%	51	53%*	97
Ob	15	48%	16	52%*	31

Back Rotation

BMI	Neutral		Rotation		**Total**
U	36	69%	16	31%*	52
N	235	75%	80	25%*	315
O	65	67%	32	33%*	97
Ob	23	74%	8	26%	31

Table 6: Muscle Fitness Results by Age and Sex
(level of significance ≥ 5%; sample size ≥10)

Age

There were no significant results between group 1: 17-21 and group 2: 22-35

Sex

	Poor		**Below Ave.**		**Average**		**Above Ave.**		**Excellent**	
	0 – 36		37 – 60		61 -119		120 - 180		181+	
Planks	n	%	n	%	n	%	n	%	n	%
Males	6	4%	15	10%*	79	50%	37	23%*	20	13%*
Females	42	12%	50	15%*	190	56%	37	11%*	19	6%*
Push-ups	0 - 2		3 - 4		5 - 20		21 - 30		31+	
Males	3	2%	1	1%	67	42%	50	32%*	35	22%*
Females	45	14%	44	13%	215	64%	22	7%*	8	2%*
Air Squats	0 - 34		35 - 49		50 - 130		131 - 200		201+	
Males	12	8%	20	13%	79	50%	44	28%*	0	0%
Females	31	9%	31	9%	197	58%	72	21%*	3	1%
Hand Grip - Dominant Hand										
Dom. Hand	0 - 18		19 - 22		23 - 37		38 - 45		46 +	
Males	2	1%	2	1%	43	27%	66	42%*	40	25%
Females	40	12%	68	21%	206	62%	12	4%*	5	2%
Hand Grip - Non-dominant Hand										
	0 - 17		18 - 21		22 - 33		34 - 44		45 +	
Males	1	1%	3	2%	42	27%	74	47%	33	21%
Females	47	14%	57	17%	212	64%	9	3%	6	2%
Balance - Dominant Foot										
	0 - 8		9 - 13		14 - 59		60 - 94		95 +	
Males	20	13%	15	10%	88	56%	23	15%	10	6%
Females	32	10%	36	11%	194	57%	39	12%	37	11%
Balance - Non-dominant Foot										
	0 - 5		6 - 10		11 - 44		45 - 87		88 +	
Males	9	6%	27	17%*	86	84%	22	14%	12	8%
Females	10	3%	32	10%*	217	64%	45	13%	34	10%

Note. Significance is considered for categories above and below average—not for average. Also, the sample sizes are often too small for significance.

Table 7: Muscle Fitness Results by BMI.
(level of significance* ≥ 5% & sample size ≥ 10)

Push-ups	Underweight		Normal		Overweight		Obese	
Norms	n	%	n	%	n	%	n	%
Poor	10	20%*	25	8%*	8	8%	8	27%
Below Ave.	10	20%	49	16%	14	15%	5	16%
Average	12	24%	72	23%	27	28%	8	26%
Above Ave.	10	20%	86	28%	24	25%	7	23%
Very Good	8	16%	50	16%	14	15%	2	6%
Excellent	1	2%	29	9%	9	9%	3	10%
Total > ave.	19	48%*	165	53%*	47	49%*	9	39%
Total	51	100%	311	100%	96	100%	31	100%
Plank								
Poor	10	20%*	28	9%*	6	6%	5	16%
Below Ave.	11	21%	76	24%*	36	38%*	13	42%*
Average	8	15%	39	12%	8	8%	6	19%
Above Ave.	14	27%	88	28%	28	29%	5	16%
Very Good	8	15%	49	16%	13	14%	2	6%
Excellent	1	2%	34	11%	5	5%	0	0%
Total > ave.	23	44%*	171	55%*	46	48%*	7	22%
Total	52	100%	314	100%	96	100%	31	100%
Squats								
Poor	8	16%	33	11%	9	9%	1	3%
Below Ave.	10	20%*	37	12%*	20	21%*	10	32%*
Average	15	29%	79	26%	28	29%	8	26%
Above Ave.	12	24%	80	26%*	14	14%*	6	19%
Very Good	6	12%	77	25%	26	27%	6	19%
Excellent	0	0%	3	1%	0	0%	0	0%
Total > ave.	18	36%*	160	52%*	40	41%*	12	38%*
Total	51	100%	309	100%	97	100%	31	100%
Balance Dom. Foot								
Poor	8	15%	27	9%*	14	14%*	3	10%
Below Ave.	7	13%	51	16%*	22	23%*	7	23%
Average	16	31%	83	27%	21	22%	4	13%
Above Ave.	14	27%	77	25%	21	22%	8	27%
Very Good	5	10%	43	14%	10	10%	6	20%
Excellent	2	4%	33	11%	9	9%	2	7%
Total > ave.	23	41%*	143	50%*	40	41%*	16	54%
Total	52	100%	313	100%	97	100%	30	100%
Balance Non-dom. Foot - no significant results								
Hand Grip Dominant & Non-dominant - no significant results								

Table 8: Mobility: Shoulder ROM & Toe Touch by Age, Sex, & BMI.
(level of significance ≥ 5%, sample size ≥10)

			Age				
Shoulder ROM	Below Ave.		Average		Above Ave.		
17-21	36	8%	275	60%	146	32%*	457
22 and older	6	14%	26	62%	10	23%*	42
Toe Touch	Below Ave.		Average		Above Ave.		
17-21	121	26%*	148	32%	189	41%*	458
22 and older	12	29%*	15	36%	15	36%*	42
			Sex				
Shoulder ROM	Below Ave.		Average		Above Average		
Male	16	10%	89	56%	53	34%	158
Female	26	8%	210	62%	102	30%	338
Toe Touch	Below Ave.		Average		Above Ave.		
Male	59	37%*	54	34%	45	28%*	158
Female	73	22%*	108	32%	158	47%*	339
			BMI				
Shoulder ROM	Below Ave.		Average		Above Ave.		
Underweight	8	15%	29	56%	15	29%	52
Normal	27	9%	187	59%	101	32%	315
Overweight	6	6%	60	63%	30	31%	96
Obese	1	3%	24	77%	6	19%	31
Toe Touch	Below Ave.		Average		Above Ave.		
Underweight	14	27%	18	35%	20	38%	52
Normal	79	25%*	108	34%	129	41%*	316
Overweight	32	33%*	24	25%	40	42%	96
Obese	7	23%	13	42%	11	35%*	31

Table 9: Mobility: Hip ROM.
(level of significance ≥ 5%, sample size ≥10)

Age

Hip ROM Dom.	Deficient		Good		
17-21	139	31%*	315	69%*	454
22 and older	20	48%*	22	52%*	42
Hip ROM Non-Dom.	Deficient		Good		
17-21	153	33%*	304	67%*	457
22 and older	22	54%*	19	46%*	41

Sex

Hip ROM Dom	Deficient		Good		
Male	67	42%*	91	58%*	158
Female	90	27%*	245	73%*	335
Hip ROM Non-Dom.	Deficient		Good		
Male	76	48%*	81	52%*	157
Female	97	29%*	241	71%*	338

BMI

Hip ROM Dom.	Deficient		Good		
Underweight	18	35%	34	65%	52
Normal	98	32%	213	68%	311
Overweight	32	33%	65	67%	97
Obese	9	29%	22	71%	31
Hip ROM Non-Dom.	Deficient		Good		
Underweight	23	44%*	29	56%*	52
Normal	104	33%*	209	66%*	313
Overweight	37	38%	60	62%	97
Obese	9	29%	22	71%	31

Table 10: Fitness Results by Dominant vs. Non-dominant Side
(level of significance* ≥ 5%, sample size ≥10)

Upper Body

Grip Strength by Hand Dominance

= Grip		Dom. Hand >		N-dom. Hand >		
n	%	n	%	n	%	**Total**
59	12%	337	69%*	88	19%*	484

Note: the average strength difference between hands was 2.75 kilos

Shoulder Joint ROM by Hand Dominance

= ROM		Dom. >		N-dom. >		
n	%	n	%	n	%.	**Total**
188	38%	74	15%*	231	47%*	493

Shoulder Joint ROM by Hand Dominance

	Neutral		Rotation dom.		Rotation n-dom. S	
Diff. Shoulder Joint ROM	n	%	n	%	n	%
ROM equal	121	44%	44	31%	22	29%
Dominant > ROM	40	15%	27	19%	8	10%
Non-dominant > ROM	113	41%	73	51%	47	61%
Total	**274**	100%	**144**	100%	**77**	100%

Chi-square (4)=14.68, p=0.05 correlation: r=.15, p=0.001

Lower Body

No significant differences were found for balance or hip joint ROM

Group C: Analysis of Fitness Results by Alignment Categories: neutral vs. deficits

The analysis of muscle fitness results by alignment includes figures based on ANOVA analysis for air squats, push-ups and planks vs. alignment, comparing results for students with neutral alignment vs. students with alignment deficits (Figures 2, 3, 4). There was no difference for grip strength or balance. Additionally, Figure 5 presents plank performance in relation to the specific alignment deficits of swayback and flatback. The analysis of mobility results by alignment includes Chi Square analysis between flexibility and shoulder joint ROM vs. alignment (Figure 6). There was no difference for hip joint ROM.

Discussion

These results provide evidence that: 1) neutral alignment is rare, and 2) alignment, muscle strength and mobility are co-related. Of the 502 student participants, only 18 had neutral alignment in all three planes. At 4% of the population, this result is similar to a study by Bricot (2008).

Compared to students with alignment deficits, those with neutral alignment were stronger; having better scores for air squats, plank and push-ups. The differences were more prominent for males for plank and push-up (Figures 4 & 5). Further investigation revealed that the alignment of the lumbar curve is particularly important to plank performance. Participants with a neutral lumbar curve scored better than those with either swayback or flatback (Figure 6). This supports the hypothesis that when the body is out of alignment, there is increased muscle tension, predisposing the body to early fatigue during exercise (Cook, 2003).

Figure 2: Air Squats by Alignment for Total Population.

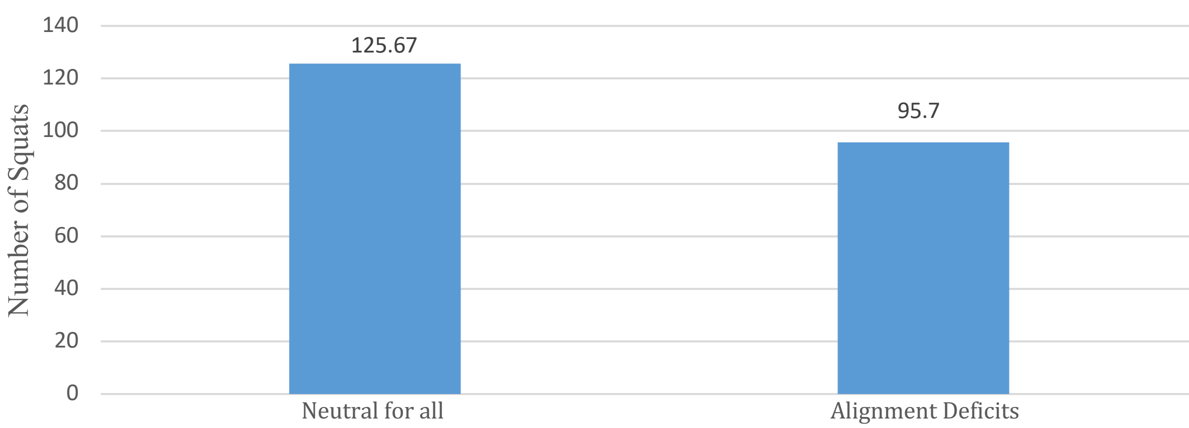


Figure 3: Push-ups by Alignment & Sex.

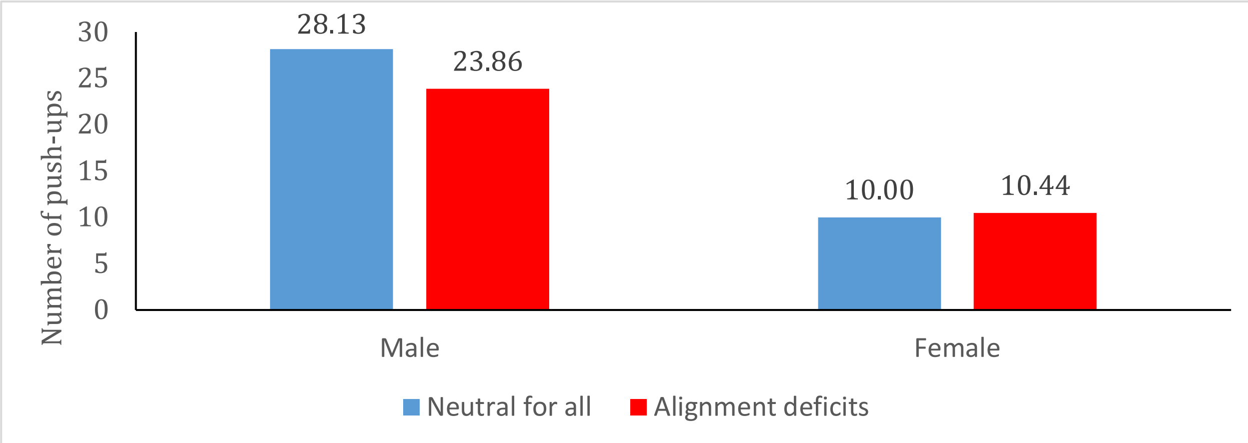


Figure 4: Plank by Alignment & Sex.

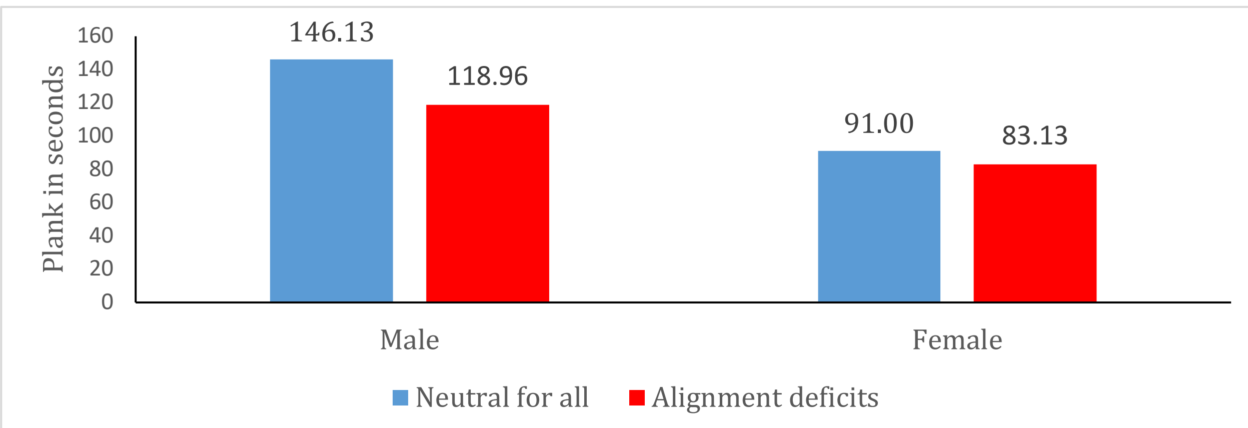


Figure 5: Plank by Specific Alignment Deficits: Swayback and Flatback.

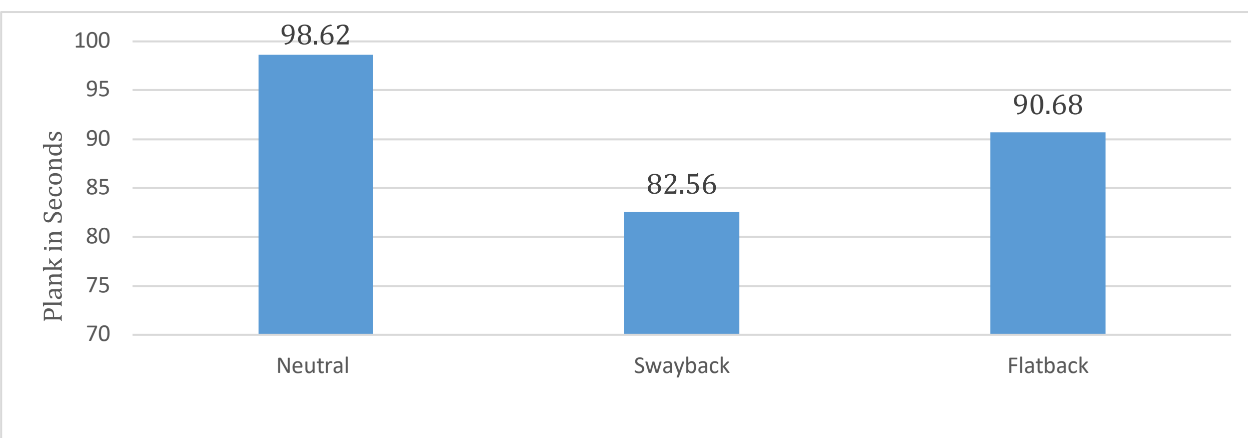
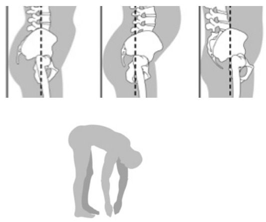


Figure 6: Chi Square Analysis of Mobility & Alignment Deficits.

Lumbar Curve by Toe Touch Flexibility

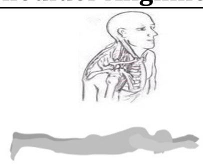


Lumbar curve	Below Ave. n	Below Ave. %	Average n	Average %	Above ave. n	Above ave. %
Neutral	84	64%	133	82%	155	76%
Sway-back	35	27%	20	12%	39	19%
Flat back	13	10%	10	6%	9	4%
Total	132	100%	163	100%	203	100%

Chi-square (4)=14.82, p=0.005 correlation: r_s= -0.10, p=0.02

Note: – pattern of decreasing flexibility for flatback to touch toes

Shoulder Alignment (frontal plane) by Shoulder Joint ROM



Shoulder Alignment	Below Ave. n	Below Ave. %	Average N	Average %	Above Ave. n	Above Ave. %
Neutral	18	44%	194	64%	100	65%
Round forward	23	56%	107	36%	55	35%
Total	41	100%	301	100%	155	100%

Chi-square (2)=6.81, p=.033;

Additionally, there were correlations between certain alignment deficits and reduced mobility: students with forward shoulders had lower scores for shoulder ROM, and students with a flat lumbar curve had lower scores for toe touch flexibility (Figure 7).

There was no difference between the students with neutral alignment compared to others for the one-foot balance test, or for grip strength, suggesting that alignment may not be important for these fitness components.

Rates of Alignment Deficits

At 47%, forward head was the most common alignment deficit in the sagittal plane (Table 1). In view of the research connecting cell phone usage to forward head, this result was expected (Twenge, 2017; Cuddy, 2015; Sang, Na, Kyung & Kyung, 2016). As the head moves forward, it can pull the shoulder girdle with it, which was the case for 37% of students with forward shoulders.

For the frontal plane, the results indicate that it is more common for students to have shoulders that are tilted rather than level and 25% had tilted hips. Additionally, the data indicated an interesting pattern of increasing instability from the knees to the ankles and foot arches.

This may be the first study to assess rotation of the shoulders, pelvis and back in the transverse plane for college students. The results were unexpectedly high and suggest that the dominance of one side of the body may be a primary source of alignment deficits for both the frontal and transverse planes. Consider the following:

- 45% of participants reported rotation through their shoulder girdle; the direction of rotation was most often towards the dominant hand (Table 1)
- 47% of participants reported rotation of the pelvic girdle; the direction of rotation was most often towards the dominant side (Table 1)
- 56% of participants had uneven shoulders; however unexpectedly, the shoulder of the non-dominant hand was just as likely to be the higher one (Table 1). A possible explanation is that some people prefer to carry their bags on the non-dominant shoulder, to keep the dominant hand free.

- 69% of participants recorded a stronger grip in their dominant hand (Table 10).
- Only 15% of participants had greater mobility in the shoulder of the dominant hand vs. 47% who had greater mobility in the shoulder of the non-dominant hand (Table 10). This result suggests that the more frequent use of the dominant hand can lead to loss of mobility of the shoulder.

Additionally, the similarity in rates of alignment deficits for the shoulders and hips indicates a relationship between the frontal and transverse planes.

Variation in Alignment and Fitness Results by Age, Sex, and BMI

The alignment results by sex indicate that female participants are less stable than males. Females had higher rates of tilted shoulders, back rotation, elbow and knee hyperextension, valgus knees, ankle pronation and low foot arches (Table 4). Sex studies with athletes have identified that, compared to males, females have higher rates of certain knee injuries, and are more prone to other injuries, due in part to differences in pelvic size and lower limb alignment, and greater joint laxity (Harmon & Ireland, 2000; Hewett et al., 2005). The findings of this study, with regards to females having higher rates of knee hyperextension, valgus, and ankle pronation supports this research. Also, the findings that females had greater hip joint ROM and flexibility may predispose them for certain injuries (Tables 8 & 9).

Some of the muscle fitness results for females were contrary to standard norms. Females had similar results as males for air squats and balance (Table 6). These results challenge the reliability of standard sex-based fitness norms.

The alignment results by age indicate that older students (22-35) have greater stability than younger students (Table 3). Older students had lower rates of forward head and shoulders, knee and elbow hyperextension, valgus knees, tilted shoulders and hips, pronated ankles, and shoulder and pelvic girdle rotation (Table 3). The only deficit that was more predominant for older students was back rotation. One possible explanation would be that with age there is a reduction in activity level and consequently, muscles lose suppleness and joints become more stable. This notion is supported by the findings that older students had lower scores for all mobility measures (Tables 8 & 9). Also, although most students aged 17-21 have reached their full height, they may not have reached their adult weight. Their muscles may be still developing, rendering their bodies less stable.

Contrary to standard fitness norms, older students had similar results as younger students for all muscle fitness tests (Table 6).

Analysis of alignment and fitness results by BMI yielded both expected and unexpected results. Expectedly, the results indicate a positive relationship between the BMI category of normal and alignment; a higher percentage of students in the normal BMI category had neutral alignment (Table 2). Additionally, students in the normal BMI category attained a higher percentage of scores above average for air squats, planks, push-ups and balance on the dominant foot, compared to students in other BMI categories (Table 7), and had either equal or higher scores for tests of mobility (Tables 8 & 9).

Students in the overweight category had more alignment deficits compared to normal weight students. They had higher rates of forward head, tilted shoulders, swayback and anterior pelvic tilt, valgus knees, back rotation and pelvic girdle rotation (Table 5). Compared to the fitness performance of normal weight students, overweight students had similar results for push-ups and a few lower results for plank, squats and balance. Additionally, overweight students had similar mobility scores with the exception of toe touch flexibility which was lower (Tables 7, 8, & 9).

It is difficult to evaluate the alignment and fitness performance of students in the obese BMI category due to the small number of participants at n=31. When distributed over performance categories, the number of participants was often below the required sample size of 10.

However, there are a few results that indicate a negative relationship between obesity and alignment, and obesity and fitness. Obese students had higher rates of knee and elbow hyperextension and pelvic rotation (Table 5) and lower results for planks, air squats and toe touch flexibility (Tables 7, 8 & 9). Other studies have linked obesity to both general postural instability and the specific deficit of anterior pelvic tilt (Sun, Wang & Wang, 2015; Son, 2016). It should be noted that one obese student was among the 18 with ideal alignment (Table 2).

Unexpectedly, the data suggests that being underweight, being deficient in muscle development, may be more of a concern for posture than overweight or obesity. Underweight students had higher rates of forward shoulders, back rotation, elbow hyperextension, anterior pelvic tilt, and tilted hips. Additionally, these students reported lower scores on push-ups, plank air squats and balance, and lower scores on hip ROM (Tables 7, 8 & 9). Also, whereas the group of 18 students with ideal, neutral alignment included 3 overweight and 1 obese student, none were underweight. At 10% of the population, underweight affects more students than obesity at 6% (Table 2), and yet physical education focuses more on overweight and obesity as a health concern.

Significance of Alignment deficits to Athletic Potential

Given the rates of alignment deficits close to 50%, it is possible to describe the typical college student as follows: their head is forward; their shoulders are tilted, and their shoulder and pelvic girdles are rotated. They may also have ankle pronation; it was reported at 43% (Table 1).

This combination of alignment deficits would disadvantage the student for athletics. The forward head position would reduce visual field, limit chest capacity affecting respiration, and the forward shift in the cervical vertebra may lead to impingement of cervical nerves and blood vessels (Gokhale, 2008; Mark, 2003). There would be an increase in the recruitment and tension of muscles supporting the head which could ripple downwards affecting the back.

The uneven and rotated shoulders would diminish shoulder mobility and exert torque on the vertebral column. The rotated pelvic girdle would also exert torque on the vertebral column and would impact gait. Instability in the vertebral column can negatively impact the development of many motor skills (Starrett, 2013). Pronated ankles reduce overall stability.

The increase in muscle tension associated with alignment deficits wastes energy and leads to early muscle fatigue during activity (Cook, 2003). The joint instability associated with alignment deficits increases the risk for injury

(Rippetoe, 2017). If these alignment deficits remain undetected, they could progress, pulling the body into a downward spiral of mobility loss and discomfort (McGill, 2007; Lynn, 2017).

Conclusions

Given that 96% of students have at least one alignment deficit, a 'neutral' body alignment is atypical. This is an important message for students who feel that their bodies are less than perfect and not suited for athletic activity. The relationships identified between alignment deficits and lower scores on muscle fitness tests suggest that muscle weakness hinders good alignment. The relationships identified between alignment deficits and mobility tests suggest that shifts in alignment are detrimental to joint range of motion and muscle suppleness. Additionally, there are results that suggest that hand dominance is a factor in creating alignment deficits in the frontal and transverse planes.

The high rate of alignment deficits and the relationships identified between alignment and fitness results point to the importance of assessment in physical education. The high rate of shoulder, hip and back rotation suggest that alignment assessments should include the transverse plane in addition to the frontal and sagittal planes. It is recommended that alignment assessments be conducted with fitness testing so that students can make the connection between alignment and muscle development.

The results demonstrate that muscle fitness and neutral alignment are mutually beneficial, and that many deficits can be reduced or overcome through improved muscle fitness. The results support the theory that stable alignment is fundamental to athletic performance. (Starrett, 2013; Rippetoe, 2017). This is important information for students seeking to improve their physical abilities.

The study points to many shortages in posture knowledge. It is recommended that further investigation be undertaken to understand why female students have more deficits than male students; why younger students have more than older students, and why underweight and overweight students have more deficits than normal weight students. Additionally, further investigation is needed to understand the influence of dominant side for alignment in the frontal and transverse planes.

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The author's qualifications are as follows: Joanna Farmer HBA, MA.

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