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CURRENT OPINION

The Case for Retiring Flexibility as a Major Component of Physical Fitness

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Abstract

Flexibility refers to the intrinsic properties of body tissues that determine maximal joint range of motion without causing injury. For many years, flexibility has been classified by the American College of Sports Medicine as a major component of physical fitness. The notion flexibility is important for fitness has also led to the idea static stretching should be prescribed to improve flexibility. The current paper proposes flexibility be retired as a major component of physical fitness, and consequently, stretching be de-emphasized as a standard component of exercise prescriptions for most populations. First, I show flexibility has little predictive or concurrent validity with health and performance outcomes (e.g., mortality, falls, occupational performance) in apparently healthy individuals, particularly when viewed in light of the other major components of fitness (i.e., body composition, cardiovascular endurance, muscle endurance, muscle strength). Second, I explain that if flexibility requires improvement, this does not necessitate a prescription of stretching in most populations. Flexibility can be maintained or improved by exercise modalities that cause more robust health benefits than stretching (e.g., resistance training). Retirement of flexibility as a major component of physical fitness will simplify fitness batteries; save time and resources dedicated to flexibility instruction, measurement, and evaluation; and prevent erroneous conclusions about fitness status when interpreting flexibility scores. De-emphasis of stretching in exercise prescriptions will ensure stretching does not negatively impact other exercise and does not take away from time that could be allocated to training activities that have more robust health and performance benefits.

1 Flexibility Defined

Flexibility refers to the intrinsic properties of body tissues that determine maximal joint range of motion (ROM) without causing injury [1, 2]. Static flexibility refers to joint ROM usually in relaxed muscle [2, 3]. Static flexibility is subjective, as the limit ROM is determined by the tester or the patient and their stretch tolerance [2, 3]. Tools used to assess static flexibility include rulers, goniometers, electrogoniometers, inclinometers, fleximeters, photography, visual estimations, and three-dimensional kinematics [4–11]. Dynamic flexibility refers to stiffness of the muscle-tendon unit within normal ROM [2, 3]. Dynamic flexibility is more objective [2, 3] and is assessed with force sensors, isokinetic dynamometers, and shear wave elastography.

The current paper is concerned with static flexibility and the sit-and-reach test. The sit-and-reach requires participants to sit on the floor or in a chair and reach toward their toes. This test is used in school fitness batteries in the United States [12, 13]. The American College of Sports Medicine (ACSM) states the sit-and-reach should be included in health-related physical testing due to the "relative importance of hamstring flexibility to activities of daily living and sports performance…" [14]. Numerous studies have examined the validity and reliability of the sit-and-reach [4, 15–50]. The test is reliable and primarily measures hamstrings flexibility.

2 Brief History of Flexibility in the United States

Clinical tests have been used to measure static flexibility (hereafter termed "flexibility") in intact humans since the early 1900s [11, 51]. In 1941, Cureton summarized research on flexibility [52]. He discussed ways flexibility

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Key Points

Flexibility has been considered a major component of physical fitness for many years, and significant time and resources are devoted to its instruction, measurement, and evaluation.

This paper proposes flexibility be retired as a major component of physical fitness because it has little predictive or concurrent validity with meaningful health and performance outcomes in apparently healthy individuals, particularly when viewed in light of the other major components of physical fitness (i.e., body composition, cardiovascular endurance, muscle endurance, muscle strength).

Because the fundamental purpose of stretching is to improve flexibility, this paper also proposes stretching does not need to be a standard component of exercise prescriptions for most populations. Other activities that cause more robust health benefits (e.g., resistance training) are sufficient for improving or maintaining flexibility, if desired.

was assessed, explained findings from studies that compared flexibility in different groups, and described stretches to improve flexibility [52]. He did not state explicitly flexibility should be a component of physical fitness, but his paper gave credence to the idea.

Throughout the 1950s and 1960s, researchers continued to study and discuss flexibility [53–62]. In 1952, Wells and Dillon created the sit-and-reach—a modification of the "Standing, Bobbing," which required participants to stand on a bench and bob down to their toes [50]. In 1954, Kraus and Hirschland reported American youth exhibited worse physical fitness (including flexibility) than European youth [58]. Their results led to the creation of the President's Council on Physical Youth Fitness and school fitness testing [12, 63]. In 1958, Guilford wrote physical educators have "recognized for a long time that flexibility of movement is important in athletic training" [64]. In 1960, Leighton wrote about the "significance of flexibility for physical educators" [59]. In 1962, Nick and Fleishman classified flexibility as one of the five components of "physical proficiency" [60]. The following year, Fleishman included tests of "extant flexibility" in a factor analysis that attempted to establish valid tests for each component of fitness [54]. In 1968, Holland communicated skepticisms and uncertainties about flexibility, and concluded flexibility and human motor performance are "probably not as highly correlated as traditionally believed" [56]. In 1980, Corbin and Noble called flexibility a "major component of physical fitness" and made claims about its health benefits [51]. The same year, the American Alliance for Health, Physical Education, Recreation and Dance established the first national health-related physical fitness battery [12]. It included the sit-and-reach.

Today, flexibility is conceptualized as part of physical fitness. The Department of Health and Human Services says flexibility is "an important component of physical fitness" [65]. The American College of Sports Medicine (ACSM) says flexibility is "important in athletic performance (e.g., ballet, gymnastics) and in the ability to carry out activities of daily living" and "maintaining flexibility…may prevent injury" [14]. The ACSM considers flexibility along with body composition, cardiovascular endurance, muscle endurance, and muscle strength, the five components of health-related physical fitness [14] (hereafter termed "major components").

The notion flexibility is important for physical fitness has led to the idea flexibility exercises (i.e., stretching) be prescribed to improve ROM. The ACSM says: "it is reasonable, based on the available evidence, to recommend individuals engaging in a general fitness program perform flexibility exercise following cardiorespiratory or resistance exercise—or alternatively—as a stand-alone program [14]." The ACSM recommends 2–3 days of stretching per week (2–4 repetitions of multiple stretches per day) [14, 66]. In the United States, 80% of personal trainers say they prescribe static stretching [67]. An international survey revealed 53% of physically active adults normally stretch, 60% stretch for 5–10 min per exercise session, and 23% stretch for over 10 min per session [68].

3 Aim

The current paper proposes flexibility be retired as a major component of physical fitness. In Sect. 4, I explain flexibility has little predictive or concurrent validity with health and performance outcomes, particularly when assessed by the sit-and-reach and when compared to other fitness components. In Sect. 5, I explain the case for retiring flexibility is also the case for decreased emphasis on stretching as a standard or necessary component of exercise prescriptions for most populations. Static stretching does not clearly and consistently improve health and function. Moreover, flexibility can be maintained or improved by exercise modalities that cause more robust health benefits than stretching (e.g., resistance training). In Sect. 6, I describe potential implications of decreased emphasis on flexibility and stretching. In Sect. 7, I counter potential misinterpretations of my position and provide final thoughts on the paradox between the lack of evidence supporting flexibility and its continued status as a major component of fitness.

4 Case for Retiring Flexibility as a *Major* Component of Physical Fitness

4.1 Mortality

Flexibility, as measured by the sit-and-reach or standing trunk flexion, is not predictive of all-cause mortality [69, 70]. Body composition [71, 72], cardiovascular endurance [73], muscle endurance [74], muscle strength [75–78], and muscle power [79] are all predictive of mortality.

4.2 Aging, Falls, Activities of Daily Living, and Gait

Flexibility declines with age [80, 81], but unlike muscle strength [82], flexibility does not predict falls in older adults [83–87]. Flexibility levels are usually greater (not always statistically) in older adults who are the most independent and functional in activities of daily living (ADL) [88–90]. Nevertheless, muscle strength is also greater in those more functional older adults [88–90]. In correlational studies, greater flexibility usually correlates with better ability to perform ADLs ($r = 0.20–0.50$) [88, 89, 91–93], but so does muscle strength [88, 89, 92, 93]. This relationship between muscle strength and ADLs has been observed numerous times in older adults [90, 94–101] and results from longitudinal studies indicate muscle strength at middle or older age *predicts* ADL performance later in life [94, 97–99].

Flexibility also correlates with gait parameters. Sit-and-reach scores correlate with walking velocity in older adults ($r = 0.40–0.42$) [93]. Also, older adults exhibit less hip extension during normal gait than younger adults [102, 103]. Nevertheless, muscle strength of ankle dorsiflexors correlates with walking velocity in older adults ($r = 0.31–0.63$) [93] and lack of plantar flexion strength during walking is a likely reason older adults walk slowly [102, 103]. Isometric knee extension ($r = 0.35–0.53$) [104] and ankle plantarflexion strength ($r = 0.36–0.41$) [105] correlate with preferred gait speed in older adults; isokinetic peak torque of knee extensors correlates with walk-turn-walk performance at comfortable ($r = 0.37$) and fast speeds ($r = 0.39$) [106]; isokinetic peak torques of hip extensors, knee extensors, and ankle plantar flexors correlate with maximal gait speed ($r = 0.52–0.63$) and stride length at habitual ($r = 0.38–0.53$) and maximal gait speeds ($r = 0.53–0.63$) [107].

4.3 Quality of Life

Sit-and-reach scores correlate positively with quality of life in early postmenopausal women ($r = 0.39–0.51$) [108]. Individuals with higher sit-and-reach scores report greater life satisfaction [109]. Yet, muscle strength also correlates positively with quality of life ($r = 0.40–0.48$) [108] and is greater in individuals who report greater life satisfaction [109–111]. Other studies have *not* observed a relationship between flexibility and quality of life, but they have observed relationships with other fitness measures and quality of life [112–114].

4.4 Injury and Pain

Sit-and-reach scores do not predict future incidence of low back pain or injury in adults [115–118], hamstring injuries in male soccer players [119], hamstring injuries in male Australian Football players [120], or lower-limb pain in adolescents [121]. Sit-and-reach scores also do not distinguish industrial workers with and without a history of low back discomfort [122].

High levels of flexibility might *increase* injury risk. In dancers, increased lower-limb ROM or "hypermobility" either increases injury risk or does not correlate with injury [123–127]. One systematic review concluded athletes with hypermobile joints are at *increased* risk of knee but not ankle injury during contact sports [128]. In addition, professional male soccer players with hypermobile joints (i.e., high Beighton scale scores [129–131]) have a "tendency" for higher risk of injury [132] and are at higher risk of injury and re-injury and have more severe injuries than players without hypermobile joints [133]. However, in professional *female* soccer players, Beighton scores are *not* predictive of injury [134]. Issues surrounding the Beighton scale are discussed elsewhere [135].

Sit-and-reach scores in male cadet soldiers who experience non-contact anterior cruciate ligament injuries over a 4-year period are *higher* at baseline (41.4 cm) than in non-injured cadets (36.5 cm) [136]. During 12 weeks of basic training, male soldiers with the lowest *and* highest sit-and-reach scores are more likely to experience lower-limb injury [137, 138]. Thus, a middle range of flexibility reflects optimal fitness in this group. However, sit-and-reach scores do not predict injuries in *female* soldiers, and female soldiers are twice as likely as male injuries to sustain injuries in basic training [139]. Finally, a recent systematic review concluded there is "moderate evidence" ankle and hamstring flexibility (e.g., sit-and-reach scores) predict musculoskeletal injury in military and civilian populations [140].

Nevertheless, other components of fitness are also risk factors for injuries. There is "strong evidence" poor cardiovascular endurance and muscle endurance (push-ups) are risk factors for musculoskeletal injuries in military and civilian athletic populations of both sexes [138, 141, 142]. Body mass index (BMI) is an independent risk factor for injuries in various athletic groups [143–146]. Squat one-repetition maximum is predictive of traumatic knee injuries in female high school athletes [147]. However, isokinetic strength of knee flexors and extensors generally does not predict hamstring strains [148] and isokinetic knee flexion and extension strength and eccentric hip abduction and adduction strength do not predict injuries in professional male soccer players [149].

4.5 Cardiovascular Outcomes

In adolescents, sit-and-reach scores do not correlate with blood pressure or resting heart rate ($r < 0.10$). Body composition and cardiorespiratory endurance correlate more strongly with these outcomes ($r = 0.10$–0.40) [150, 151]. In 7605 adults, there were no differences in blood pressure, ratio of total cholesterol to high-density lipoprotein, and lung function between individuals with high and low sit-and-reach scores [109]. Mixed findings exist on whether sit-and-reach scores differ between individuals with and without metabolic syndrome [152–154]. Cross-sectional [155] and longitudinal studies [156] suggest sit-and-reach scores in healthy adults may predict arterial stiffening, independent of other fitness components.

4.6 Correlations with Other Fitness Components

Flexibility generally does not correlate with body composition [157–167], cardiovascular endurance [168], muscle endurance [117], or muscle strength [160, 164, 165, 169], although exceptions exist [89, 170]. Body composition [71, 72], cardiovascular endurance [73], muscle endurance [74], and muscle strength [75–78] all correlate with mortality and various health outcomes. Absence of correlations between flexibility and other fitness components indicates flexibility is a distinct trait, but not one particularly important for health and function.

4.7 Performance in Physically Demanding Occupations

Sit-and-reach scores do not correlate with performance on simulated firefighting tasks [164, 171, 172], simulated military tasks [173, 174], or a simulated police foot chase [175]. Sit-and-reach scores do not distinguish individuals who pass and fail a Special Forces entry examination [174]. A study that included field observations of airmen and interviews and focus groups with Air Force personnel concluded flexibility is the least important component of fitness [176]. Finally, Hauschild and colleagues pooled correlation coefficients from 27 studies that assessed relationships between physical fitness and task performance in physically demanding military jobs [177]. Flexibility demonstrated the weakest correlations ($r \leq 0.16$). Correlations between task performance and cardiovascular endurance ($r = \sim 0.30$–0.60), muscular endurance ($r = \sim 0.35$–0.60), and muscular strength ($r = \sim 0.40$–0.60) were stronger. Body composition, cardiovascular endurance, muscle endurance, muscle strength, and agility are all more important than flexibility for physically demanding work [164, 171–177].

4.8 Sports Performance

The current paper focuses on flexibility in the general population. Nevertheless, millions of individuals compete in sports and a discussion on flexibility in sports helps form the larger picture of flexibility and physical function.

Some sports require above average levels of flexibility. In Cureton's 1941 paper, swimmers exhibited greater hamstrings flexibility and greater ROM in ankle plantarflexion, shoulder flexion, and trunk extension than controls [52]. Dancers exhibit greater hamstrings flexibility and greater ROM in ankle plantarflexion, hip abduction, and hip external rotation than controls [178–180]. Swimmers and gymnasts have more flexible hamstrings than other athletes (e.g., baseball, basketball) [181, 182]. Sit-and-reach scores are ~ 8 cm greater in male powerlifters than controls, but their back scratch scores are 23 cm lower [183]. Shoulder ROM is greater in Olympic-style weightlifters than in controls, American Football players, and bodybuilders [184]. However, shoulder ROM is less in bodybuilders and American Football players than controls [184].

In other athletic groups, flexibility levels often are the same as in controls, do not correlate with athletic performance, and do not differentiate athletes of different playing abilities. Such findings date back to early flexibility research and were pointed out by Holland in 1968 [56]. In 1938, Wettstone found shoulder and trunk flexibility did not predict gymnastics ability (i.e., coaches rating) in novice and experienced male gymnasts [185]. In Cureton's 1941 paper, most correlations between trunk, shoulder, and ankle flexibility and "a wide variety of physical performances other than swimming" were "insignificant" and not even reported [52]. In 1950, Sigerseth reported American Football players were *less* flexible than controls at 20 of 21 joints [62]. In 1961, Burley and colleagues reported weak or no associations ($r \leq 0.16$ or -0.16) between upper- and lower-limb flexibility and upper- and lower-limb power (e.g., broad jump) in high school females. In 1966, Bushey reported a correlation of $r = 0.28$ between "stool flexibility test" scores and modern dance performance as rated by judges [186]. In the same study, correlations between dance performance and strength and power were stronger ($r = 0.36, 0.38$) [186].

More recent studies reveal similar findings. Sit-and-reach scores are comparable between elite and sub-elite athletes in 100-m sprinting [187], 200-m sprinting [188], handball [189], climbing [190, 191], parachuting [192], and taekwondo [193]. Sit-and-reach scores are not statistically different between starters and non-starters in American Football [194, 195], selected and non-selected players in Australian

Football [196, 197], or first and second team youth soccer players [198]. However, sit-and-reach scores are higher in six starters (19.5 cm) than six non-starters (10.6 cm) on a female college volleyball team [199].

Sit-and-reach scores also do not correlate with kayak time trial performance [200] or surrogates of ice hockey performance [201], although higher levels of trunk, hip, and groin flexibility appear necessary for hockey goalies [202, 203]. In endurance runners, faster runners sometimes have *lower* sit-and-reach scores [204]. In addition, flexibility and running economy are *inversely* related in some [205–209] but not all studies [210–212].

Notably, in several of the above studies, body composition [187, 192], cardiovascular endurance [192, 194], muscle endurance [190], and muscle strength [186, 187, 189, 191, 195, 196] were more strongly correlated with athletic performance than flexibility. Even in sports where high levels of flexibility are required, other fitness components must be considered [213–216]. Sit-and-reach scores in international swimmers are 3.5 cm greater than in national swimmers [213]. However, international swimmers are also stronger and more powerful than their national counterparts [213]. Lower-limb strength, not flexibility, generally correlates most strongly with surrogates of swim performance [215, 216].

5 Case for De-emphasizing Stretching in Exercise Prescriptions for Most Populations

A fundamental purpose of fitness testing is to acquire information to guide exercise prescriptions. Declaration of flexibility as a major component of physical fitness has led to the notion flexibility exercises (i.e., stretching) should be prescribed to improve flexibility. According to guidelines, the primary purpose of stretching is to improve flexibility [14]. Therefore, if flexibility is not a major component of fitness (Sect. 4), then stretching is not needed in exercise prescriptions for many populations. Moreover, to the extent flexibility might need improvement, this does not necessitate a stretching prescription. Stretching is not the only activity in which muscles and tendons are lengthened and thus it is not the only activity that increases flexibility.

5.1 Increased Flexibility After Stretch or Resistance Training

Static stretching twice or more per week for several weeks increases sit-and-reach scores 9–43% [217–225] (Table 1). Other measures of ROM also increase after weeks of stretch training [226–242]. Increased stretch tolerance [241, 243, 244] and changes in muscle-tendon unit mechanical and viscoelastic properties (e.g., reduced passive stiffness) [235, 245] likely explain increased flexibility after stretch training. These mechanisms are discussed elsewhere [246, 247].

Nevertheless, resistance training—a mode of exercise that involves repeated actions of muscle lengthening and shortening against external load *through full ROM*—increases sit-and-reach scores (10–25%) [224, 248–255] (Table 2) and other measures of ROM equal to stretching [256–261] (Table 3). Other papers also report increased flexibility after resistance training but do not contain explicit statements about the exclusion of supplemental stretching [262–268]. Finally, in DeLorme's pioneering work on resistance training, orthopaedic patients increased ROM after training [269].

Aerobic exercise for 10–24 weeks increases sit-and-reach scores 10–17% [250, 270, 271]. In older adults, sit-and-reach scores increase 30–150% after step mat training [272, 273] and 14% after "functional" body weight exercises [274]. Finally, one study of older adults reported ~5% improvements in sit-and-reach scores after aerobic, resistance, balance, and static stretch training [275].

5.2 Improved Health and Function After Stretch or Resistance Training

Static stretching sometimes improves outcomes other than flexibility. Kokkonen et al. reported high-volume static stretching over 10 weeks (3× per week, 40-min sessions) improved muscle strength and endurance ~30% in young adults [219]. Gait kinematics in older adults also improve after static stretch training [276], and the potential for static stretching to improve cardiovascular outcomes is an emerging area [277, 278].

Nevertheless, static stretch training often does not improve muscle strength [224, 235, 279] or other health outcomes [280, 281]. In older woman, muscle strength *decreased* 1–5% after 12 weeks of static stretching (2 sessions per week; 45-min sessions) [279]. In the same study, muscle strength improved 10–20% after combined resistance, aerobic, agility, or power exercise [279]. One meta-analysis concluded "there is conflicting information regarding both the relationship between flexibility interventions and functional outcomes or daily functioning" in older adults [281]. Finally, in contrast to stretch training, aerobic and resistance training are known to positively impact a range of health outcomes [66, 282–287].

5.3 Injury Prevention with Stretch or Resistance Training

Stretch training to prevent injury is questionable. For delayed-onset muscle soreness, "evidence from randomised studies suggests that muscle stretching, whether

Table 1 Summary of studies (non-exhaustive search) that have reported on the effect of static stretch training on the sit-and-reach test

References	*n*	Sex	Age (years)	Intervention	Duration (weeks)	Frequency (days/week)	FLEX volume # of stretches × rep #	Sit-and-reach change (%)
Kokkonen et al. 2007 [219]	19	F/M	~23	Control	10	N/A	N/A	−2
	19	F/M	~23	FLEX	10	3	15×3 reps (40 min)	+18
Simao et al. 2011 [224]	20	F	34	Control	16	N/A	N/A	0
	20	F	34	FLEX	16	3	N/A	+34
	20	F	35	RT	16	3	6–15RM	+20
	20	F	35	RT + FLEX	16	3	6–15RM	+35
Kamandulis et al. 2013 [218]	62	F/M	15	Control	5	N/A	N/A	+2
	55	F/M	15	FLEX—test×4	5	2	Test stretch× 4 reps	+5
	54	F/M	15	FLEX—1×4	5	2	1×4 reps	+13
	58	F/M	15	FLEX—4×4	5	2	4×4 reps	+22
Wong and Figueroa 2014 [225]	14	F	56	Control	8	N/A	N/A	+4
	14	F	57	FLEX	8	3	38×1 rep (50 min)	+21
Mayorga-Vega et al. 2014 [312]	23	F/M	10	PE	8	N/A	N/A	+3
	22	F/M	10	PE + FLEX	8	2	4×3 reps (5 min)	+9
Mayorga-Vega et al. 2014 [313]	23	F/M	11	PE	8	N/A	N/A	+2
	22	F/M	11	PE + FLEX	8	2	5×3 (5 min)	+16
Mayorga-Vega et al. 2015 [220]	61	F/M	13	PE	8	N/A	N/A	+1
	60	F/M	13	PE + FLEX 1 day	8	1	4×2 reps (4 min)	+7
	59	F/M	13	PE + FLEX 2 days	8	2	4×2 reps (4 min)	+9
Nishiwaki et al. 2015 [222]	8	M	42	Control	4	N/A	N/A	−2
	8	M	45	FLEX	4	5	10×3 reps (30 min)	+43
Hadjicharalambous 2016 [217]	12	M	16	Soccer	4	N/A	N/A	−4
	11	M	16	Soccer + FLEX	4	4×2	NR×2 reps (16 min)	+29
Mayorga-Vega et al. 2016 [221]	45	F/M	8	PE	9	N/A	N/Z	0
	51	F/M	9	PE + FLEX 1	9	2	4×2 reps (4 min)	+14
	45	F/M	8	PE + FLEX 2	9	2	4×2 reps (4 min)	+16
Rodriguez Fernandez et al. 2016 [223]	22	NR	17	Soccer	7	N/A	N/A	−8
	81	NR	19	Soccer + FLEX	7	6	4×2 reps (12 min)	+25

F female, *FLEX* flexibility training (static stretch training), *M* male, *NR* not reported, *PE* physical education class

conducted before, after, or before and after exercise, does not produce clinically important reductions in delayed-onset muscle soreness in healthy adults" [288]. Stretching also does not prevent injuries in military training [289–291], running [292], or sports [246, 292–294] although evidence in sports is mixed [295]. In Shrier's 1999 review, he concluded "[t]he basic science literature supports the epidemiologic evidence that stretching before exercise does not reduce the risk of injury" [246]. Finally, one systematic review concluded resistance training reduces sports injuries to less than one-third [293].

Jamtvedt et al. tested if stretching before and after physical activity influenced soreness and risk of injury in active adults [68]. Over 2000 participants were randomized to control (no stretching) or an internet-based stretching program of 14 min of static stretching before and after physical activity for 12 weeks. Compliance with the program was "moderate." Stretching reduced both bothersome soreness and injuries to muscles, ligaments, and tendons. However, stretching did not produce clinically important or statistically significant reductions in all-injury risk. All-injury risk was not different between groups, thus stretching must have increased risk of injuries not measured. The investigators concluded participant preferences, time and effort required to stretch, and the small probable benefits of stretching need to be weighed to determine if active individuals should engage in stretching [68].

Stretch training for some *existing* conditions is also questionable. Cochrane reviews on stretch training for contracture [280], mechanical neck disorders [296], and ankle fractures [297] have all concluded there is limited to no evidence stretching improves pain or function in these conditions. Finally, with fibromyalgia, stretching does not improve pain intensity, physical function, fatigue, or

Table 2 Summary of studies that have reported on the effects of resistance training (without any supplemental stretching) on the sit-and-reach test

References	*n*	Sex	Age (years)	Intervention	Duration (weeks)	Frequency (days/week)	RT load	Sit-and-reach change (%)
Barbosa et al. 2002 [249]	8	F	65	Control	10	N/A	N/A	−2
	11	F	69	RT	10	3	Moderate loads	+13
Fatouros et al. 2002 [250]	8	M	71	Control	16	N/A	N/A	0
	8	M	72	CV	16	3	N/A	+5
	8	M	70	RT	16	3	55–80% 1RM	+11
	8	M	70	RT + CV	16	3	55–80% 1RM	+12
Fatouros et al. 2006 [251]	10	M	70	Control	24	N/A	N/A	−2
	14	M	71	RT—low load	24	3	40% 1RM	+12
	12	M	70	RT—moderate load	24	3	60% 1RM	+22
	14	M	71	RT—high load	24	3	80% 1RM	+26
Faigenbaum et al. 2007 [252]	22	M	14	RT	9	2	8–15RM	+10
Simao et al. 2011 [224]	20	F	34	Control	16	N/A	N/A	0
	20	F	34	FLEX	16	3	N/A	+34
	20	F	35	RT	16	3	6–15RM	+20
	20	F	35	RT + FLEX	16	3	6–15RM	+35
Junior et al. 2011 [253]	20	M	NR	Control	10	N/A	N/A	0
	20	M	NR	RT—1 set	10	3	8–12RM	~15
	20	M	NR	RT—2 sets	10	3	8–12RM	~25
Adams et al. 2001 [248]	7	F	52	Control	8	N/A	N/A	+2
	12	F	51	RT	8	2	70–80% 1RM	+8
Moraes et al. 2013 [255]	10	M	16	Control	12	N/A	N/A	+4
	14	M	15	RT—periodized	12	3	65–95% 1RM	+17
	14	M	15	RT—non-periodized	12	3	65–95% 1RM	+22
Leite et al. 2017 [254]	9	M	24	Control	24	N/A	N/A	+17
	12	M	24	RT—1 set	24	3	8–12RM	+25
	13	M	24	RT—3 sets	24	3	8–12RM	+13
	13	M	24	RT—5 sets	24	3	8–12RM	+17

CV cardiovascular/aerobic training group, *F* female, *FLEX* flexibility training (static stretch training), *M* male, *NR* not reported, *RT* resistance training group, *1RM* one-repetition maximum

health-related quality of life when compared to land-based aerobic training [298]. Resistance training is superior to stretch training for improving pain and function in fibromyalgia [299].

6 Implications of Reduced Emphasis on Flexibility and Stretching

6.1 Flexibility

Millions of flexibility tests are conducted each year in schools in the United States [300]. Thus, one implication of retiring flexibility as a major component of fitness is the simplification of test batteries and saved time and resources dedicated to its instruction, measurement, and evaluation.

A second implication is the prevention of erroneous conclusions about fitness when flexibility is low or average. When Bobo and Yarbrough found similar sit-and-reach scores between aerobic dance instructors and controls, they concluded "aerobic dance teachers should participate in general flexibility stretching activities…" [301]. When Scott found sit-and-reach scores from *elite* field hockey players were low compared to norms, they concluded the players should improve flexibility to "avoid the possibility of injury" [302]. In both examples, the groups supposedly in need of improving flexibility were already physical active and presumably in better overall physical condition than controls. The issue was not their low/average flexibility but the importance placed on flexibility. Such misinterpretations occur regularly and on a large scale when university students are taught low/average flexibility scores are necessarily problematic and should be improved by stretching.

Table 3 Summary of studies that have reported on the effects of resistance training (without any supplemental stretching) on joint range of motion as measured by tests other than sit-and-reach

References	*n*	Sex	Age (years)	Intervention	Duration (weeks)	Frequency (days/week)	RT load	Test	Joint	Change (%)
Nobrega et al. 2005 [257]	10	F/M	~21	Control	12	N/A	N/A	Flexitest	Global	0
	11	F/M	~21	FLEX	12	2	N/A		Global	~+27
	13	F/M	~21	RT	12	2	8–12RM		Global	−1
	9	F/M	~21	RT + FLEX	12	2	8–12RM		Global	~+22
Monteiro et al. 2008 [258]	10	F	37	Control	10	N/A	N/A	Flexometer	Shoulder	−1 to 2
									Knee	+1
									Hip	+2–5
									Trunk	−2 to 13
	10	F	37	RT	10	3	8–20RM		Shoulder	+3 to 37
									Knee	−1
									Hip	+15 to 24
									Trunk	+136 to 146
Santos et al. 2010 [261]	8	F	25	Control	8	3	N/A	Goniometer	Shoulder	−1 to 1
									Trunk	−2 to 1
	8	F	24	RT—UL	8	3			Shoulder	+5 to 12
									Trunk	+29 to 37
	8	F	27	RT—AA	8	3			Shoulder	+5 to 14
									Trunk	+31 to 38
Morton et al. 2011 [259]	12	F/M	23	Control	5	N/A	N/A	Goniometer	Shoulder	+11
									Knee	+31
									Hip	0–1
	12	F/M	22	FLEX	5	3	N/A		Shoulder	+15
									Knee	+103
									Hip	+8 to 26
	12	F/M	22	RT	5	3	Not reported		Shoulder	+30
									Knee	+92
									Hip	+14 to 66
Carneiro et al. 2015 [256]	28	F	68	RT—2 days	12	2	10–15RM	Fleximeter	Hip	+3 to 26
	25	F	67	RT—3 days	12	3	10–15RM		Hip	+13 to 19
Ribeiro et al. 2017 [260]	30	F	22	RT	16	3	8–20RM	Fleximeter	Shoulder	0–11
									Hip	0–1
									Trunk	+1 to 4
	28	M	22	RT	16	3	8–20RM		Shoulder	+2 to 12
									Hip	+1 to 2
									Trunk	0–6

AA agonist/antagonist alternating sets, *CV* cardiovascular/aerobic training group, *F* female, *FLEX* flexibility/stretch training, *M* male, *RT* resistance training group, *UL* upper-/lower-body alternating sets, *1RM* one-repetition maximum

6.2 Stretching

Decreased emphasis on stretching for most populations would ensure stretching does not attenuate adaptations to resistance exercise if performed *before* exercise. Stretches held for > 60 s acutely reduce muscle force [303]. Stretching also reduces repetitions completed and training volume attained during one session of resistance exercise [304, 305]. In a 10-week study, stretching before resistance exercise attenuated training volume and hypertrophy [306]. But stretching did not attenuate strength gains in the same study [306] or in other studies [224, 307]. Notably, stretching *before* resistance exercise does not *ameliorate* neuromuscular adaptations [224, 306, 307].

A second implication of reduced emphasis on stretching is improved training efficiency. Exercise modalities that cause more robust health benefits than stretching increase flexibility (Sect. 5.1). Thus, if individuals participate in these other modalities, stretching can be removed from their prescriptions. Lower levels of flexibility in the general population are probably due, in part, to reduced physical activity [308, 309]. Thus, leisure-based activities or formal exercise prescriptions of aerobic or resistance exercise should suffice to maintain or restore functionally relevant levels of flexibility in most populations. The practical implication is reduced session duration, which might improve exercise adherence, as time is a perceived barrier to exercise [310]. Alternatively, time previously dedicated to stretching can be reallocated to (a) performing additional aerobic or resistance exercise or (b) practicing functional tasks (i.e., specificity) rather than attempting to indirectly improve task performance by improved flexibility from stretching (i.e., transfer). Notably, in the study by Kokkonen et al., participants completed 2 h of stretching per week for 10 weeks to increase muscle strength ~ 30% [219]. Thus, practitioners and their clients should consider whether stretch training is an effective and efficient use of time.

7 Closing Remarks

7.1 What This Paper is Not Saying

First, this paper is not saying flexibility is completely irrelevant for health and function; or that it should never be evaluated; or that it should be removed from educational curricula. This paper argues flexibility be demoted from a major component to perhaps a secondary component of health-related physical fitness for most populations.

Second, this paper is not saying research on flexibility should stop. New research might continue to show a middle range of flexibility levels desirable for health and function [137, 138]. This would make flexibility akin to body composition as assessed by body mass index, where both low *and* high scores reflect poorer fitness.

Third, this paper is not saying stretching never be prescribed or there are never any benefits from stretching. This paper argues stretching generally does not improve health and function in apparently healthy individuals, particularly when compared to improvements from other exercise. This paper also argues stretching is not an essential component of exercise prescriptions and time previously dedicated to stretching can be reallocated to activities that cause more robust health benefits, including improved flexibility. Nevertheless, many adults enjoy stretching [68], and personal preferences should be considered.

Fourth, this paper is not a critique of dynamic stretches (e.g., walking lunges). Many dynamic stretches are body weight calisthenics and are different to static stretches due to the volitional neural drive required to perform the movements.

7.2 Flexibility Paradox and Moving Forward

The history of flexibility as a major component of physical fitness can be summarized as sustained research interest with overall unconvincing evidence of theorized benefits, followed paradoxically by continued recommendations for its measurement. The ACSM's position paper on exercise prescriptions includes only one paragraph on "benefits of flexibility exercise" and most of the paragraph is not about benefits [66]. Yet, the ACSM considers flexibility a component of fitness and recommends stretching to improve it [14, 66]. Moreover, the *Physical Activity Guidelines for Americans* say health benefits of flexibility activities are "unknown and it is unclear whether they reduce risk of injury" [65]. Yet, the *Guidelines* say "[f]lexibility is an important part of physical fitness" [65].

Some researchers have noticed the paradox and issues surrounding flexibility. In 2012, the Institute of Medicine recommended tests of flexibility *not* be included in youth fitness testing because of a "lack of evidence for an association between flexibility tests and health outcomes…" [12]. In addition, in the development of the National Institute of Health's Toolbox for Assessment of Neurological and Behavioral Function, only 8% of experts said flexibility is relevant to motor function [311]. Flexibility tests were not included in the final Toolbox [311].

8 Conclusion

Flexibility has been researched for over 100 years. Its track record is unimpressive, particularly when viewed in light of other components of physical fitness. Flexibility lacks predictive and concurrent validity value with meaningful health and performance outcomes. Consequently, it should be retired as a major component of fitness. Because the fundamental purpose of stretching is to improve flexibility, the case for retiring flexibility is also the case for a decreased emphasis on stretching as a standard or necessary component of exercise prescriptions for most populations. Functionally relevant levels of flexibility can be maintained or restored with exercise modalities that cause more robust health and performance benefits. Implications of retiring flexibility include simplification of test batteries; saved time and resources dedicated to its instruction, measurement, and evaluation within test batteries; and prevention of erroneous conclusions about fitness status when flexibility scores are interpreted. Implications of decreased emphasis on stretching include improved training efficiency and safeguarding against negative impacts on other parts of exercise prescriptions.

Compliance with Ethical Standards

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