The One-On-One Column provides scientifically supported, practical information for personal trainers who work with apparently healthy individuals or medically cleared special populations.

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The Biomechanics of the Push-up: Implications for Resistance Training Programs

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SUMMARY

THE PUSH-UP IS WIDELY USED BY FITNESS PROFESSIONALS TO DEVELOP UPPER-BODY STRENGTH, POWER, AND LOCAL MUSCULAR ENDURANCE. ALTHOUGH THE LOAD DURING A PUSH-UP IS LIMITED BY AN INDIVIDUAL'S BODYWEIGHT AND ANTHROPOMETRY, MANY BIOMECHANICAL VARIATIONS OF THE EXERCISE CAN BE PERFORMED. THESE VARIATIONS MAY INVOLVE ALTERING HAND AND FOOT POSITIONS, WHICH IMPACTS MUSCLE RECRUITMENT PATTERNS AND JOINT STRESSES. THE IMPLICATIONS OF THESE VARIATIONS MAY BE OVERLOOKED WITH RESPECT TO THE INDIVIDUAL NEEDS AND GOALS OF THE CLIENT.

INTRODUCTION

The push-up has long been advocated as a means to assess local muscular endurance of the upper body. A variety of timed and untimed push-up tests are commonly employed as part of a fitness assessment, and these tests have been validated across a wide range of populations (23). Moreover, research shows a high correlation between push-up ability and the number of bench press repetitions performed as a percentage of body weight (1), thus providing an efficient and inexpensive alternative to free weight testing.

In fitness settings, push-ups are widely used to develop upper-body strength, power, and muscular endurance. They are staple exercises in fitness and gym classes; they are used by strength and conditioning professionals to train athletes in sports such as baseball (10), boxing (22), and martial arts (13), and they play a prominent role in the basic training programs of the U.S. Military (18). Plyometric push-ups are considered essential for optimizing stretch-shortening cycle–induced adaptations for the upper body (21).

Although the load during a push-up is limited by an individual's bodyweight and anthropometry, many biomechanical variations of the exercise can be performed to alter muscle activity by providing either a lesser or greater challenge to the target musculature. These variations most often involve altering hand and foot positions, which impacts muscle recruitment patterns and joint stresses (3,15). Other variations include using various implements such as unstable surfaces, suspension training devices, and specially designed

Table 1
Biomechanical data pertaining to the standard push-up

Relative load	69% of bodyweight in top position (2)
	75% of bodyweight in bottom position (2)
Compressive spinal loading on L4/L5	1,838 N (1)
Prime mover mean muscle activation normalized to maximum voluntary contraction	Pectoralis major 61% (1)
	Triceps brachii 66% (1)
	Anterior deltoid 42% (1)
Upper-body stabilizer and synergist muscle activation normalized to maximum voluntary contraction	Latissimus dorsi 11% (1)
	Biceps brachii 4% (1)
	Posterior deltoid 17% (4)
	Upper trapezius 45% (3)
	Middle trapezius 18% (3)
	Lower trapezius 27% (3)
	Serratus anterior 56% (3)
Core muscle activation normalized to maximum voluntary contraction	Psoas 24% (1)
	External oblique 29% (1)
	Internal oblique 10% (1)
	Transverse abdominis 9% (1)
	Rectus abdominis 29% (1)
	Rectus femoris 10% (1)
	Erector spinae 3% (1)

push-up equipment. However, the implications of these variations often are not well understood with respect to the individual needs and goals of the client. Therefore, the purpose of this column is 2-fold: first, to examine the research pertaining to the biomechanical aspects of the push-up; second, to make practical recommendations for their application to exercise performance.

THE BIOMECHANICS OF THE PUSH-UP

The standard push-up requires a general stiffening of the knee joints, hip joints, pelvis, and spine to keep the body in a straight line from head to feet while the shoulders and elbows flex and extend to raise and lower the body and the scapulae retract and protract to facilitate glenohumeral range of motion. Table 1 showcases biomechanical data found in the literature regarding the standard push-up exercise.

Push-ups can be performed with a multitude of variations to bring about different muscular recruitment patterns. The knee push-up shortens the lever, which reduces bodyweight loading to 54% in the top position and 62% in the bottom position (19) and substantially reduces prime mover (9) and core musculature requirements (11).

Perhaps the most popular variations are achieved by altering hand position. Although a number of potential hand positions exist, the most common classifications include wide base (150% shoulder width), normal base (shoulder width), and narrow base (50% shoulder width) (9). It is commonly believed that the wide base activates the pectoralis major to a greater degree than the other positions, whereas the narrow base optimizes the activation of the triceps brachii (8). This is consistent with the basic principles of applied anatomy. Specifically, the pectoralis major is a primary horizontal flexor, and flaring the elbows would seemingly improve the muscle's length-tension relationship, thereby facilitating its ability to generate greater force (12). On the other hand, a narrow base with the elbows held close to the body would place the pectorals in a biomechanically disadvantageous position, thus requiring greater force output from the triceps brachii. However, electromyographic (EMG) studies evaluating muscle recruitment patterns during push-up performance

Table 2 Push-up variations for novice, intermediate, and advanced exercisers	
Novice variations	Wall push-up
	Torso-elevated push-up
	Knee push-up
Intermediate variations	Standard push-up (figure 1)
	Wide base push-up
	Narrow base push-up
	Rapid countermovement push-up
	Torso-shifted forward push-up
	Torso-shifted rearward push-up
	Feet-elevated push-up
	Upper-body suspended push-up (e.g., TRX) (figure 2)
	Hands on stability ball push-up Hands on BOSU ball push-up
	Perfect Push-up
	Handle grip push-up
	Fall push-up (from knees)
	Staggered base push-up
	Alternating side-to-side push-up
	One legged push-up
	Between-bench push-up(figure 3)
Advanced variations	Clapping push-up
	Self-assisted one-arm push-up (figure 4)
	One arm push-up
	Weighted-vest push-up
	Weighted push-up (plates on back)
	Elastic band-resisted push-up (figure 5)
	Chain push-up (draped over back) (figure 6)

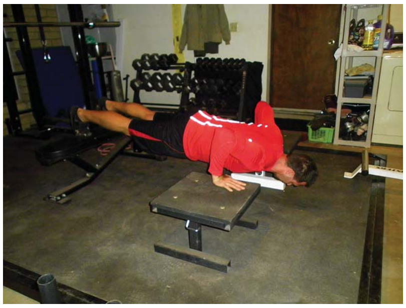

Figure 3. Between-bench push-up.

suggest that narrow base push-ups not only elicit greater activation of the triceps brachii compared with the wide base position but also promote superior activation of the sternal head of the pectoralis major as well (4,9).

What is not clear in these studies is whether performance was carried out in the transverse plane (i.e., elbows flared) or the sagittal plane (i.e., elbow close to the body). Contrary to popular belief, when the hands are placed in a very narrow position, it tends to encourage flaring of the elbows, orienting movement into the transverse plane. If these studies did indeed show greater activity of the sternal head in the sagittal plane, further research is warranted to clarify the reason for this apparent paradox. Moreover, given that the clavicular head of the pectoralis major is a primary shoulder flexor (17), it can be theorized that push-ups performed in the sagittal plane would maximize the activity of this portion of the muscle. To the authors' knowledge, this has yet to be investigated.

In addition, shifting the torso forward or rearward relative to the hands

Figure 1. Standard push-up.

Figure 2. Upper-body suspended push-up.

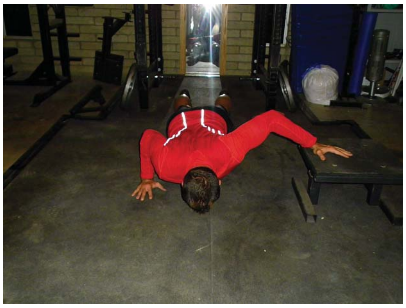

Figure 4. Self-assisted one-arm push-up.

Figure 5. Elastic band-resisted push-up.

affects the muscular recruitment patterns. Shifting the torso forward relative to the hands results in an increased pectoralis major activity and a decreased triceps brachii activity compared with the normal base position. Shifting the torso rearward relative to the hands results in slightly increased pectoralis major and triceps brachii activity (9).

Foot position also is often altered to vary muscle recruitment. Recently, Ebben et al. (5) assessed the peak vertical ground reaction forces of push-up variations including the standard push-up and those performed from the knees, with feet elevated on a 30.5-cm box and a 61.0-cm box, and with hands elevated on these boxes. Push-ups with the feet elevated produced a higher ground reaction force than all other push-up variations. When expressed as a percentage of total body mass, the order from least to greatest load progressed from the hands elevated on a 61.0-cm box (41% of bodyweight), to the knee push-up (49%), to the hands elevated on a 30.5-cm box (55%), to the regular push-up (64%), to the feet elevated on a 30.5-cm box (70%), and finally to the feet elevated on a 61.0-cm box (74%).

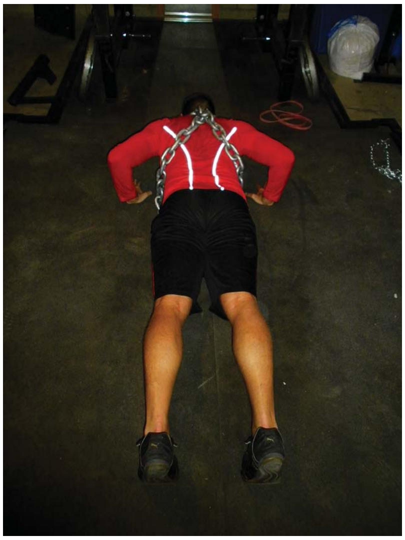

Figure 6. Chain push-up (draped over back).

Another push-up variation involves the use of unstable surfaces. Compared with standard push-ups, BOSU (Hedstrom Fitness, Ashland, Ohio) push-ups have been shown to increase the activity of some of the scapular stabilizers, namely, the upper, mid, and lower trapezius fibers; however serratus anterior activity was diminished (20). Research by Lehman et al. (15) reported that elevating the feet above the hands had a greater stimulus on scapulothoracic stabilizing musculature than placing the hands on an unstable surface (i.e., stability ball). From a training perspective, it is more challenging and demanding for the shoulder girdle stabilizers to perform push-ups with the feet elevated on a bench and the hands on the ground than to perform push-ups with the hands on a stability ball and the feet on the ground.

Lehman et al. (14) found that push-ups with the hands placed on a stability ball significantly increased the activation of triceps brachii. Stability ball push-ups also increased pectoralis major, rectus abdominis, and external oblique activation compared with push-ups on a bench from the same angle, whereas push-ups with the feet placed on a stability ball did not affect muscle activity compared with push-ups with the feet on a bench from the same angle. In addition, Marshall and Murphy (16) showed that triceps brachii and abdominal EMG activity was significantly greater when performing push-ups off stability balls compared with stable surfaces from flat and elevated positions. These results indicate that the stability ball seems to only increase the muscle activity during exercises where the unstable surface is the primary base of support. From a muscle activation standpoint, it therefore appears to be more effective to perform exercises such as stability ball and BOSU push-ups in comparison with stable surface push-ups as long as torso angle remains constant and the hands are placed on the unstable piece of equipment rather than the feet.

Push-ups can also be performed with suspension devices and implements specially designed to facilitate changes in hand positions. Beach et al. (2) showed that suspended push-ups activated more core musculature than standard push-ups. One such device, the BOSU Perfect Push-up, is purported to be biomechanically engineered to achieve better results from push-up workouts. The efficacy of this claim was investigated by Youdas et al. (24) who used EMG to evaluate the muscle activity in the Perfect Push-up versus standard push-ups. Muscle activation was evaluated during the performance of push-ups using 3 different hand positions: normal base, wide base, and narrow base. The muscles studied included the triceps brachii, pectoralis major, serratus anterior, and posterior deltoids. Analysis of EMG failed to show any significant differences between the groups, leading researchers to conclude that Perfect Push-up handgrips do not seem to increase the muscular recruitment when compared with the standard push-ups.

Finally, speed of movement can be altered to change push-up biomechanics. Explosive push-ups have been compared in terms of peak force, rate of force development, and peak impact force. Garcia-Masso et al. (7) examined the fall push-up (an explosive push-up starting from a tall-kneeling position, falling to a knee push-up position, and returning to the tall-kneeling position), jump push-up (an explosive push-up starting from standard position, where the upper body leaves the ground and becomes airborne before returning to standard position), and countermovement push-up (a rapid push-up characterized by fast eccentric, reversal, and concentric phases but does not involve leaving the ground) and found that the countermovement push-up, which was performed with maximal speed, exhibited the highest peak force and rate of force development. Given that this is the only variation that does not encounter impact forces, it appears that the countermovement push-up is a safe and effective choice for explosive variations if one wishes to maximize the aspects of upper-body power. Clapping push-ups have been shown to outperform standard, slow eccentric, 1 hand on medicine ball, staggered hands, hands on 2 balls, 2 hands on 1 ball, rapid countermovement, 1 arm, and alternating plyometric push-up variations in pectoralis major and triceps brachii activity (6). Advanced forms of plyometric push-ups could be problematic for individuals with back issues, given that an alternating plyometric push-up using a medicine ball has been shown to induce 6,224 N of compressive forces on the lumbar spine (6).

Additional alterations can be employed to decrease or increase the challenging nature of the exercise. For example, wall push-ups (leaning forward with hands against the wall) and knee push-ups (knees on the floor) are appropriate for those with limited upper-body strength, whereas push-ups using 1 arm or 1 leg can make the movement sufficiently challenging even for those who are highly fit. Furthermore, a weighted vest, elastic bands, chains, and/or various unstable implements can be employed to further challenge the upper-body musculature. Table 2 illustrates some push-up variations, categorized into the levels of difficulty.

CONCLUSION

Push-ups can be an excellent exercise for improving muscle strength and endurance. It is imperative that practitioners possess adequate knowledge of push-up variations to optimize the challenge on the target musculature without compromising proper form and risking injury. The biomechanical information contained herein can serve as a guideline to prescribe proper progressions and regressions to achieve desired outcomes.

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