Effects of shoulder girdle dynamic stabilization exercise on hand muscle strength

Article *in* Isokinetics and Exercise Science · March 2015

DOI: 10.3233/IES-140560

Alena Kobesova
Charles University in Prague

Angela Sardina
University of North Carolina at Wilmington

Ross Andel
Arizona State University

Isokinetics and Exercise Science 23 (2015) 21–32
DOI 10.3233/IES-140560
IOS Press

Effects of shoulder girdle dynamic stabilization exercise on hand muscle strength

Alena Kobesova[a,*], Jan Dzvonik[a], Pavel Kolar[a], Angie Sardina[b] and Ross Andel[b,c]
[a]*Department of Rehabilitation and Sports Medicine, Second Medical Faculty, Charles University and University Hospital Motol, Prague, Czech Republic*
[b]*School of Aging Studies, University of South Florida, Tampa, FL, USA*
[c]*International Clinical Research Center, St. Anne's University Hospital, Brno, Czech Republic*

Received 7 September 2014
Accepted 22 September 2014

Abstract.
BACKGROUND: Shoulder girdle stabilization influences hand strength but the effects of functional training remain unknown.
OBJECTIVE: To determine the influence of shoulder girdle stabilization on hand muscle strength.
METHODS: Handgrip strength (with hand in neutral position, supination, pronation) and tripod pinch strength were measured in 20 healthy volunteers (10 in training/control groups) weekly over six weeks. The training *consisted of six specific* Dynamic Neuromuscular Stabilization (DNS) exercises performed five times per week. The exercises were designed to obtain maximum joint stability within the shoulder.
RESULTS: Using mixed effects models, the training group showed significant improvement relative to the control group on all measures of hand muscle strength ($p < 0.05$). The gains were particularly pronounced in handgrip strength in the neutral position (dominant hand: Estimate = 0.26, standard error [SE] = 0.04, $p < 0.001$; non-dominant hand: Estimate = 0.23, SE = 0.03, $p < 0.001$). That is, the training group gained about 0.25 standard deviations over the control group per session for a total of 1.5 standard deviations (about 27 Newtons) across all sessions.
CONCLUSIONS: Shoulder girdle exercises based on DNS may generate clinically significant gains in hand muscle strength.

Keywords: Upper extremity, hand-held dynamometry, functional stabilization, Dynamic Neuromuscular Stabilization, rehabilitation

1. Introduction

Handgrip strength depends on the synergistic coordination between finger and wrist flexors and extensors. It is an important component in the proper execution of daily living activities as well as in various sports movements. Hand strength training is one of the most important activities used to treat pathological conditions such as neurological conditions after stroke, spinal cord injury, multiple sclerosis, myopathy, peripheral nerve injury etc., as well as in many orthopedic conditions (upper extremities fractures and/or soft tissue damage, joint dysfunction, burn injury etc.), but also while trying to improve daily or athletic performance.

Many studies have emphasized the critical influence of elbow or shoulder position on hand muscle strength [1–7]. For example, Alexander et al. [8] demonstrated that coordinated control of the shoulder girdle muscles is necessary to properly position the hand for delicate manipulation. However, to the best of our knowledge, only one study to date assessed the effectiveness of shoulder girdle stabilization on hand muscle strength [9]. Specifically, Thomas et al. [9] used only general resistance training of upper extremities and still found significant gains in hand-

*Corresponding author: Alena Kobesova, Department of Rehabilitation and Sports Medicine, Second Medical Faculty, Charles University and University Hospital Motol, V Uvalu 84, Prague 5, 159 00, Czech Republic. Tel.: +420 224 43 9264; Fax: +420 224 439 220; E-mail: alenamudr@me.com.

ISSN 0959-3020/15/$35.00

grip strength after eight weeks of intervention. More research is needed to improve the understanding of the efficacy of training to improve shoulder girdle stability on hand muscle strength. This is particularly so given the critical role of shoulder girdle function for hand muscle strength in individuals with and without hand muscle strength problems.

We built on this research by examining the effects of an exercise promoting maximum joint stability (i.e., fully functionally centrated exercise) on hand muscle strength in the pronated, neutral and supine position, and tripod pinch strength. The intervention was based on the proximal Dynamic Neuromuscular Stabilization (DNS) exercise paradigm [10–12], which includes a comprehensive stabilization of all elements of the trunk. Trunk and shoulder girdle stabilization is an important factor in the overall function of upper body musculature, presumably including the hand muscles. We hypothesized that a 6-week intervention with an exercise program designed to stabilize the shoulder girdle would have significant effects on hand muscle strength.

2. Methods

2.1. Participants

A total of 20 healthy volunteers, all female students from the Physiotherapy Program at the 2nd Medical Faculty, University Hospital Motol, Prague, Czech Republic, between 18 and 26 years of age, participated in the study. Eighteen individuals were right handed, two were left handed. The first 10 participants were assigned to the training group. An additional 10 participants were recruited to form the control group. General characteristics of each group are given in Table 1. Exclusion criteria were injury, pain or any symptomatic neurologic, orthopedic or musculoskeletal dysfunction, and any sport activity performed on a competitive level or more frequently than twice a week. During the study participants were allowed to perform non-strenuous recreational sports activity twice a week. Written informed consent was obtained from all participants. The study was approved by the ethics committee at 2nd Medical Faculty, University Hospital Motol, Prague, Czech Republic.

2.2. Assessments

Using the CITEC digital dynamometer (Citec, C.I.T. Technics, Haren, The Netherlands) we assessed maximal isometric handgrip strength following the standardized testing procedure [13]. Tripod pinch strength was also assessed. During the testing, the participant was seated on an adjustable chair without armrests (Fig. 1A). The participant's posture was adjusted to maintain an upright spine with the head in neutral position and eyesight orientation in a horizontal plane, shoulders relaxed. In order to place the pelvis in a neutral position, the participant was directed to bear weight on her ischial tuberosities. The hips were positioned at 90 degrees of flexion and slight abduction, with both feet supported on the ground. The tested arm was adducted along the trunk with 90-degree elbow flexion. To test handgrip strength, three forearm positions were utilized: 1) pronation; 2) neutral position; and 3) supination.

When measuring tripod pinch strength, the forearm was kept in the neutral position. The other arm was relaxed along the trunk (Fig. 1B). Participants received instruction to maintain the testing posture during the whole process of measurement and were familiarized with the dynamometer. The test was performed three times on each hand for each testing position: handgrip with the forearm in neutral position, pronation, supination and then tripod pinch first on the dominant, second on the non-dominant hand. The participant was continually verbally encouraged by the test administrator to develop maximum isometric grip (pinch) strength. Maximum force (in Newtons) was automatically displayed by the dynamometer after five seconds of isometric grip (pinch). Only the test administrator was able to read the values, the participant was not made aware of the values achieved. There was approximately a 45-second rest interval between each trial. In accordance with Mathiowetz et al. [13] the mean of the three trials was used for statistical analysis. To reduce measurement error, only trials that were within 10% of one another were averaged.

Testing was performed between 12 and 6 p.m. once a week with a seven-day interval between measurements. A total of seven measurements were obtained from each participant. The first measurement was taken before introducing the training program to the training group. Then subsequent measurements were taken each week with the last measurement occurring after six weeks.

2.3. Intervention

DNS represents a new rehabilitation strategy based on the principles of developmental kinesiology and

Table 1
Descriptive characteristics of the sample at baseline assessment

	Training group				Control group				
Variable	Mean	SD	Min	Max	Mean	SD	Min	Max	p-value[a]
Age (years)	23.3	2.0	18.0	25.0	24.3	1.1	23.0	26.0	0.180
Height (m)	1.70	0.6	1.62	1.80	1.70	0.5	1.64	1.77	0.648
Weight (kg)	63.2	7.5	56.0	80.0	59.4	3.5	54.0	67.0	< 0.001
Body mass index (kg/m^2)	21.8	1.2	20.6	24.7	20.5	0.9	19.3	22.0	0.010
Hand muscle strength (in Newtons)									
Tripod pinch DH	82.5	11.3	69.0	99.0	80.6	6.3	70.0	87.0	0.648
Tripod pinch NDH	80.2	10.9	66.0	96.0	77.6	5.9	71.0	87.0	0.517
Handgrip overall DH	205.6	13.1	187.3	228.7	220.7	8.4	209.3	234.0	0.007
Handgrip overall NDH	199.0	14.6	180.0	221.3	207.9	11.5	190.0	228.7	0.148
Handgrip pronation DH	199.8	13.1	180.0	226.0	207.4	8.8	190.0	222.0	0.147
Handgrip pronation NDH	197.4	13.3	178.0	218.0	194.2	13.8	178.0	218.0	0.605
Handgrip neutral DH	206.0	13.4	188.0	232.0	231.8	8.3	220.0	242.0	< 0.001*
Handgrip neutral NDH	199.8	12.7	182.0	224.0	216.4	13.3	196.0	240.0	0.010
Handgrip supine DH	211.0	15.6	190.0	230.0	223.0	13.8	198.0	240.0	0.086
Handgrip supine NDH	199.8	20.0	180.0	228.0	213.0	14.8	196.0	236.0	0.111

Notes. DH = dominant hand; NDH = non-dominant hand. [a]p-values are based on independent samples t-test statistics; *Statistically significant after Holm-Bonferroni correction for multiple comparisons.

A B

Fig. 1. (A) Handgrip strength testing position; (B) Tripod pinch strength testing position.

the neurophysiological aspects of a maturing postural-locomotor system. The DNS approach compares the individual's stabilizing pattern with the stabilization developmental pattern of a healthy infant [10,11]. The treatment approach emphasizes training of natural postural-locomotion patterns as defined by developmental kinesiology. The brain must be properly stimulated and trained to automatically activate optimal movement patterns that are necessary for co-activation of the stabilizers. This can be achieved by the activation of the stabilizers when placing the patient in developmental positions, as done in this study.

The training group performed a home-based training program five times a week for six weeks. Each training session consisted of six exercises performed in the following order: 1) prone static; 2) quadruped static; 3) quadruped dynamic rock forward; 4) bear position; 5) side-sitting with dominant arm support; and 6) side-sitting with non-dominant arm support. Overall, one exercise session took up to 25–30 minutes to complete, including 1-2 minutes of rest between each position. The following 4 positions were used in the ex-

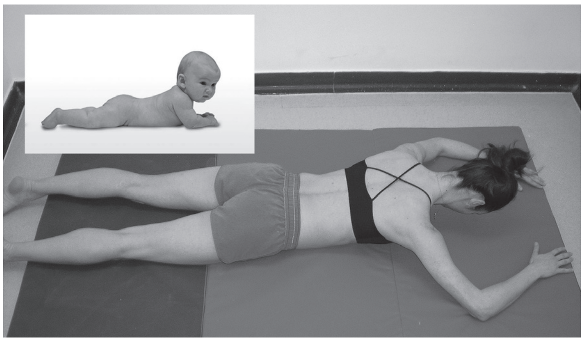


Fig. 2. Exercise in a prone position corresponding to a natural prone position of an infant at 3 months of developmental age. Initial position: Prone, elbow support, approximately 125- to 135-degree angle between the trunk and the arm. Zones of support: Medial epicondyles of bilateral elbows, bilateral anterior superior iliac spines and pubic symphysis. Instructions: Focus on elbow support, spine elongation, pulling down the shoulder blades, chin tuck, hold the position as long as you are not fatigue and your shoulder blades adhere to the ribcage.

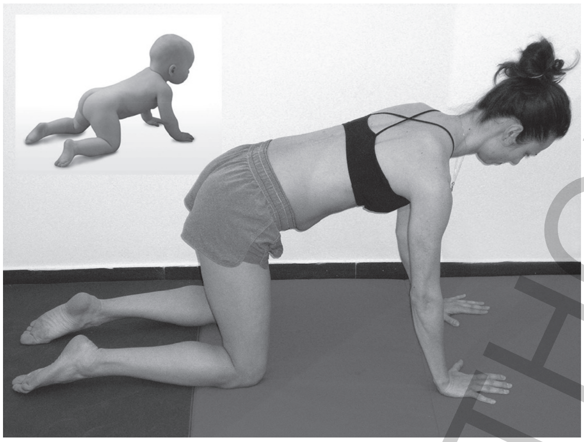


Fig. 3. Exercise in a quadruped position corresponding to a natural quadruped position of an infant at 9 months of developmental age. Initial position: The patient is in a quadruped position using hands and knees for support. The shoulder girdles are positioned over the well-supported hands. The hip joints are in slight external rotation, positioned above the supported knees, while the shins and feet converge. The entire spine and the trunk are upright. Zones of support: proportional support and weight bearing throughout the entire palms (weight distribution must be proportional on all metacarpophalangeal joints – i.e. equally on the thenar and hypothenar areas). Instructions: Focusing on support and weight bearing through the palms, elongating the spine, tucking the chin. Slowly, shift your head and trunk forward and stay in this position for approximately 5 seconds, then return to initial position. Do only as many repetitions as you can perform while maintaining the proper stereotype with correct shoulder girdle and hand stabilization.

ercise program: 1) prone position (Fig. 2) for the prone static exercise; 2) quadruped position (Fig. 3) for the quadruped static and quadruped dynamic rock forward

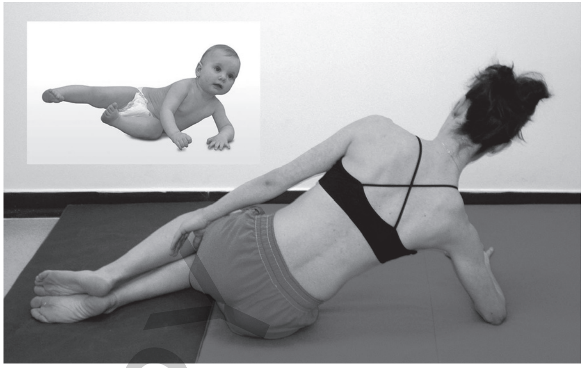


Fig. 4. Exercise in side-sitting position corresponding to a natural side-sitting position (rolling over phase) of an infant at 7 months of developmental age. Initial position: Side-sitting, supporting elbow is in line with the bottom greater trochanter, top leg in front of the bottom leg or resting on the bottom leg, slight hip and knee flexion on both legs. Zones of support: medial epicondyle of the bottom elbow, bottom greater trochanter. Instructions: Focus on support and weight bearing through the medial epicondyle of the supporting elbow and bottom trochanter area, pull the bottom shoulder blade caudally, elongate the spine, tucking the chin.

exercise; 3) side-sitting position (Fig. 4) for the side-sitting with dominant and non-dominant arm support exercise; and 4) "bear position" (Fig. 5) for the bear position exercise. Prior to initiation of the program, the participants were instructed by a Certified DNS Therapist on how to set up correct exercise positions. When instructing the participants, the correct "functionally centrated" shoulder girdle position (i.e., position of the maximum shoulder stability) and hand position were emphasized [10,11]. Each participant had to be able to feel and recognize functionally centrated (correct) versus decentrated (incorrect) position of the shoulder girdle and hand, as well as be able to adjust the position correctly. Then, for the actual exercise, the participant was asked to hold the proper position isometrically as long as possible. Once a fatigue occurred and decentration of hand, shoulder or scapula emerged (see Figs 2–5 legends) the exercise in the position was terminated.

Depending on fatigue, an exercise in one position took from approximately 30 to 120 seconds. The prone, side-sitting and bear positions represented isometric static exercises, while the quadruped position was utilized both for isometric static as well as for dynamic "rock forward" exercises (Fig. 3). This dynamic modification was also exercised only as long as the proper stereotype with correct shoulder girdle and hand stabilization was maintained.

Fig. 5. Exercise in "bear" position corresponding to a natural position (verticalization stereotype phase) of an infant at 12 months of developmental age. Initial position: The patient is in a quadruped position using hands and tip toes for support. The entire spine and the trunk are elongated, shoulder blades adhere to the rib cage, chin tucked, knees and ankles must not collapse inward. Zones of support: proportional support and weight bearing throughout the entire palms (weight distribution must be proportional on all metacarpophalangeal joints – i.e. equally on the thenar and hypothenar areas) and tiptoes. Instructions: Focusing on support and weight bearing through the palms, elongating the spine, tucking the chin. Hold the position as long as you are not fatigued and your shoulder blades adhere to the ribcage.

2.4. Statistical analysis

All measures of grip strength were normally distributed, with tolerable skewness and kurtosis. The outcome measures were converted into z-scores before main analysis in order to allow comparisons between tripod pinch and handgrip performance, which were measured on largely different scales. The intervention and control groups were tested at different time points. Although the same calibrated instrument was used, there were some noticeable baseline group differences unlikely to be attributable to differences in strength. Therefore, the z-scores calculated separately for each group were used.

There were no missing data in this dataset. We used mixed effects models in SAS (SAS Institute, Cary, NC, version 9) [14] procedure MIXED [15] to evaluate differences in grip strength over time as a function of assignment to the intervention vs. control group. Mixed effects modeling is an advanced statistical method to account for repeated measures which build directly on repeated measures analysis of variance [16]. The models estimate fixed effects of time (i.e., change in performance over time), treatment (i.e., intervention vs. control group performance), and a time-by-treatment interaction (i.e., differences in performance over time as a function of group). However, mixed effects models also include subject-level random effects that account for inter-individual differences in performance which may affect change. They also offer great flexibility with respect to the error variance structure, allowing the model to adjust exceptionally well to the actual structure of the data (creating a good model fit). In the final models, we specified unstructured covariance matrix to account for variance in scores over time and the correlation across repeated measurements of the same participant, hence allowing the scores to vary freely. This model specification yielded the best model fit. Since there were group differences in body mass index (BMI), this variable was entered as a covariate.

To examine whether hand muscle strength changed in a non-linear fashion over measurement occasions, quadratic effects of time were examined in addition to the conventional linear effects. The models with quadratic terms for time added did not yield a superior model fit over the linear models. Therefore, only models with time modeled in a linear fashion are shown.

A two-tailed 0.05 level of significance was used throughout. Holm-Bonferroni correction [17] was used to adjust the level of statistical significance for multiple comparisons (or a bias towards type I error).

3. Results

Sample baseline characteristics are presented in Table 1. Participants in the control and training groups did not differ in age or in height and weight, but the training group participants had significantly greater BMI. Further, after Holm-Bonferroni correction was applied, the control group was significantly stronger than the intervention group in handgrip strength in the neutral position with the dominant hand. All other differences did not reach the corrected level of statistical significance. It is relevant to note that mixed effects models, by including within-subjects random effects, account for potential bias by baseline differences to some extent.

The main results generated by the mixed effects models are presented in Table 2, and Figs 6 and 7. With regard to the tripod pinch strength using the dominant hand, the performance did not change significantly over the follow-up measurement when the entire sample was considered (see the estimate for time). In addition, there were no baseline differences on this measure. However, there was a significant group-by-

Table 2
Differences between training vs. control group participants in performance on main outcome measures over time

Outcome	Estimate	SE	p-value
Tripod pinch strength DH			
Change across assessments	0.00	0.02	0.823
Baseline group differences	0.02	0.55	0.971
Change by group	0.11	0.03	< 0.001*
Tripod pinch strength NDH			
Change across assessments	0.01	0.02	0.617
Baseline group differences	−0.06	0.54	0.919
Change by group	0.10	0.03	0.001*
Handgrip strength DH			
Change across assessments	0.03	0.02	0.132
Baseline group differences	−0.45	0.55	0.423
Change by group	0.19	0.03	< 0.001*
Handgrip strength NDH			
Change across assessments	−0.01	0.01	0.685
Baseline group differences	0.09	0.53	0.866
Change by group	0.16	0.02	< 0.001*

Notes. Estimate = unstandardized regression coefficient; SE = standard error of measurement; DH = dominant hand; NDH = non-dominant hand. *Statistically significant after Holm-Bonferroni correction for multiple comparisons.

time interaction indicating that the training group overall exhibited a significantly greater increase in tripod pinch strength with the dominant hand when compared to the change in performance in the control group. Specifically, the training group showed performance gains that exceeded the performance in the control group by 0.11 standard deviation (SD) units with every testing session. Therefore, over the study period, the intervention group outgained the control group by about 0.66 SD units (6 times 0.11). Arguably an improvement over 0.5 SD units can be considered a clinically meaningful improvement. Practically, when we pooled the SDs given for the two groups in Table 1 for tripod pinch, dominant hand, we obtained a SD of about 9.0 Newtons. Therefore, the value of 0.66 SD units represents an increase in strength in the training group over the control group by about 6 Newtons over the course of the study. The same pattern of results was also observed for the non-dominant hand with a group-by-time interaction effect of about the same magnitude. These results are presented graphically in Fig. 6.

With respect to handgrip strength (see Table 2 and Fig. 7), any change in performance overall was again non-significant. However, we again found a significant group-by-time interaction indicating greater performance gains in the intervention group at a rate of 0.19 SD units per testing session, hence indicating an average performance gain with the intervention of more than a full SD, which is represented by 13.25 Newtons based on pooled SD. This result was replicated with the non-dominant hand, with the intervention group outgaining the control group by an average of 0.16 SD units per session over the course of the study.

Results for handgrip strength at individual positions are shown in Table 3. The results point to (a) consistent pattern across positions and (b) the greatest difference with respect to change in performance occurring in the neutral position for both the dominant and non-dominant hand. Specifically in the neutral position, the gains reached about 1.5 SD over the course of the study, which corresponds to a net difference of about 26.7 Newtons based on a pooled SD of 17.1.

All interaction effects for change in strength by group remained statistically significant after Holm-Bonferroni correction was applied.

4. Discussion

We used a novel rehabilitation approach, the DNS [10–12], to examine whether exercise promoting optimal proximal shoulder girdle stabilization would positively influence distal handgrip strength. Research illustrates that shoulder and elbow angles have significant effects on handgrip strength [1–6]. However, not much attention has been given to the quality of shoulder girdle stabilization in this context. Specifically, shoulder girdle stabilization is not defined by one static position but by the quality of muscle coordination in all possible joint positions. The lack of proximal stabilization may limit the ability of the subject to exert maximum effort [18]. In turn, this may limit hand muscle strength [9]. Therefore, we set out to test the effect of a fully "centrated" (i.e., promoting maximum shoulder girdle stability) DNS-based exercise on hand muscle strength.

Our results support the notion that this method of shoulder girdle stabilization has significant effects on proximal dynamic stabilization and distal segment (hand) strength, particularly with the hand in the neutral position. Significant increases identified in the training group (relative to the control group) were consistently in excess of 1 standard deviation over the study's six-week duration, which can be considered highly clinically significant. In neutral position specifically, the gains reached about 1.5 SD (or about 26.7 Newtons). The training group applied exercises in four DNS-based developmental positions that we considered to be especially demanding on the quality of shoulder girdle muscle coordination. The quality of muscle coordination and shoulder blade stabilization

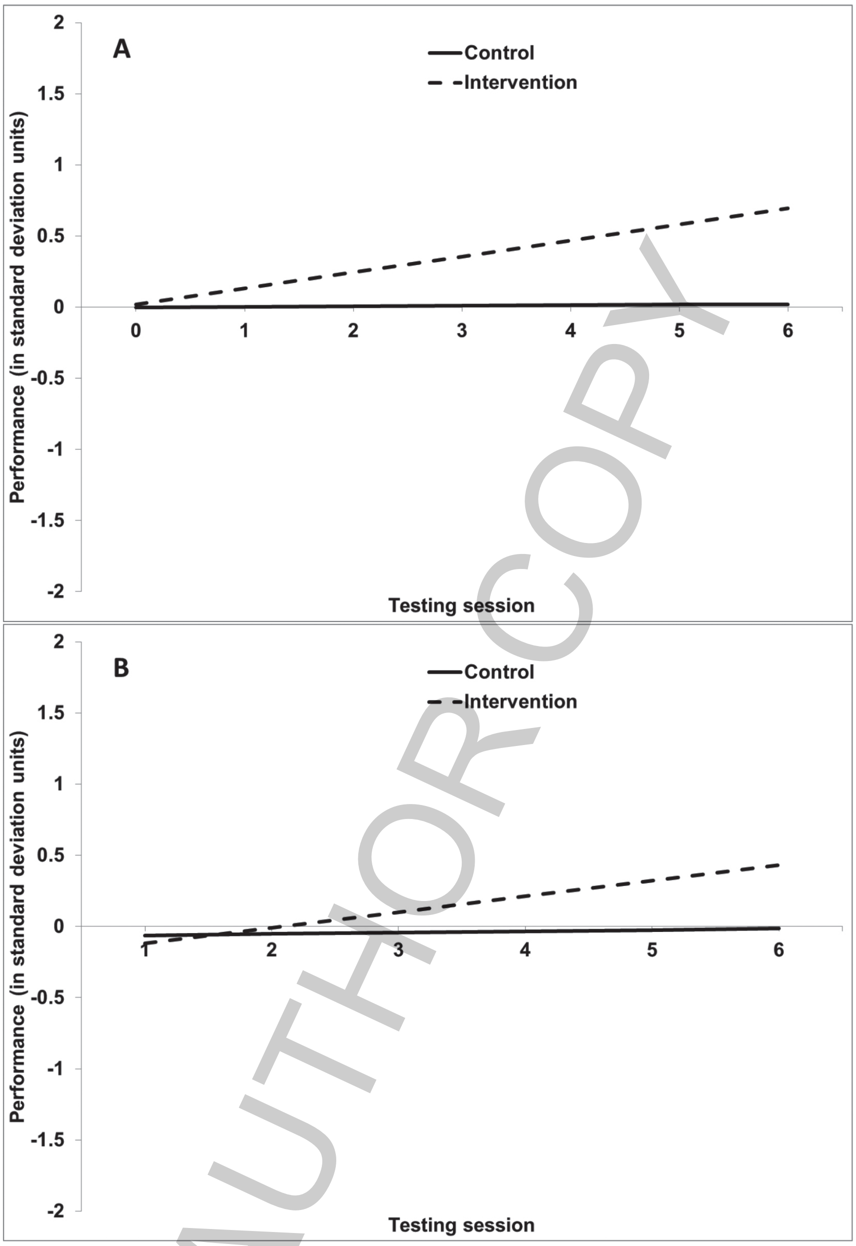


Fig. 6. Graphical presentation of change over time in pinch grip strength for the intervention and control group participants using the dominant hand (A) and non-dominant hand (B).

as well as hand centration (i.e. proportional loading of all the palm and wrist sections) was stressed heavily during the initial training session over the quantity of repetitions or exercise endurance. The participants were specifically instructed to stop any exercise as soon as insufficient stabilizing pattern (e.g. scapular winging, shoulder protraction, elbow flexion or hyperextension, or hypothenar overloading) occurred. The protocol was reviewed and corrections to the exercises were made during weekly assessments, increasing the likelihood of optimal stabilization in all four positions. Future research should evaluate whether the same DNS protocol could be applied to various sport populations to determine whether improved shoulder girdle stabilization and grip strength relates to better sport performance and reduction of movement system painful syndromes. Or if the proposed approach can lead to improvements in individuals with grip strength issues,

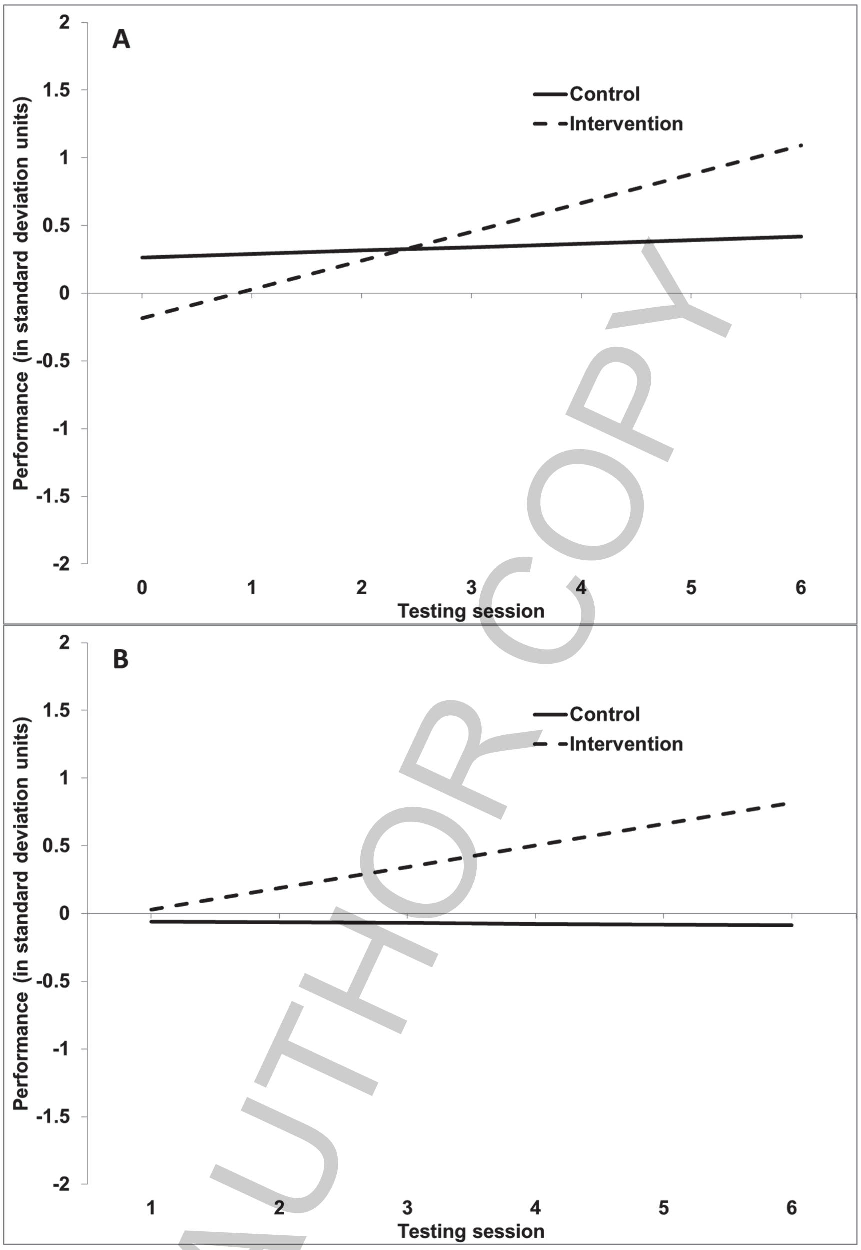


Fig. 7. Graphical presentation of change over time in overall handgrip strength for the intervention and control group participants using the dominant hand (A) and non-dominant hand (B).

such as the elderly and/or those with arthritis, where improved grip strength may be an important contributor to quality of life, functional ability, and independence.

Stability (and instability) of the shoulder girdle is ill-defined [19]. In a comprehensive review, Veeger and van der Helm [19] discussed that hand movement is dependent on three-dimensional mobility of the shoulder complex, which in turn is dependent on coordination of the trunk muscles. Pectoralis major and latissimus dorsi directly transfer arm forces to the thorax, serratus anterior and the rhomboids press the scapula on the thorax, providing a stable base for the humeral motions [19]. Scapular winging can be of various causative origins and presents with neuromuscular imbalance in the scapulothoracic stabilizer muscles. This results in various painful syndromes in the neck, shoulder girdle and upper back areas [20]. It is accom-

Table 3
Differences between training vs. control group participants on individual measures of handgrip strength over time

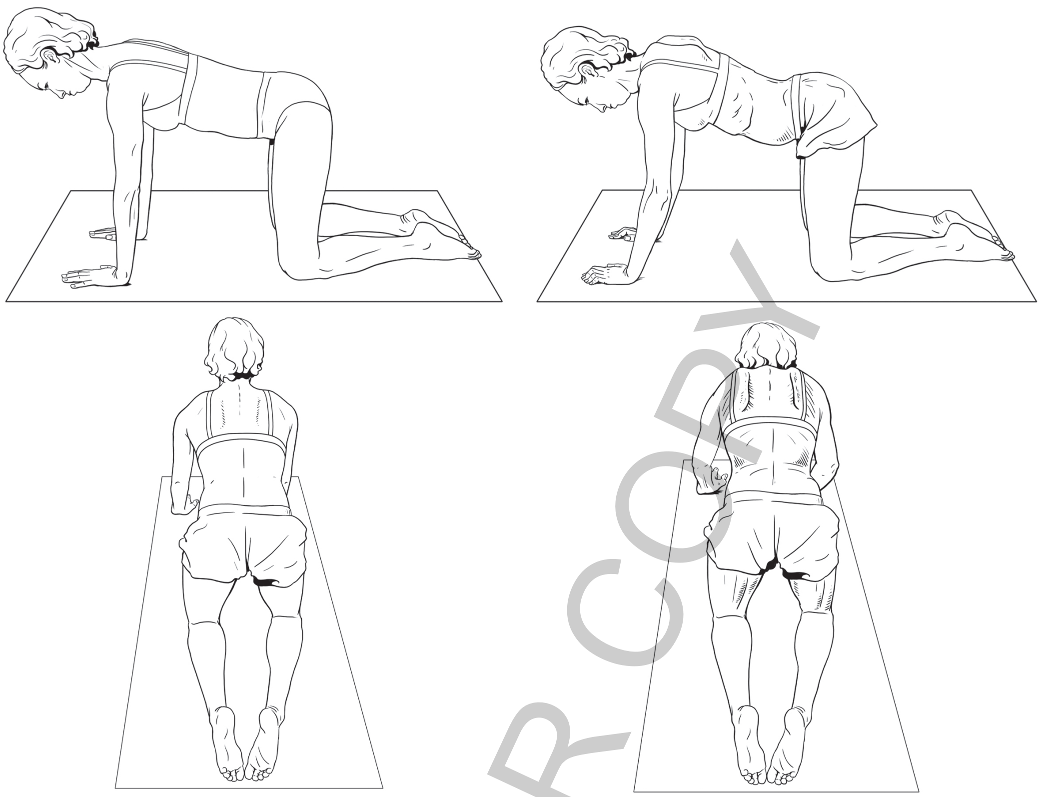
Outcome	Estimate	SE	p-value
Handgrip strength pronation DH			
Change across assessments	0.04	0.02	0.103
Baseline group differences	−0.16	0.57	0.777
Change by group	0.14	0.04	< 0.001*
Handgrip strength pronation NDH			
Change across assessments	0.00	0.03	0.908
Baseline group differences	0.29	0.51	0.567
Change by group	0.12	0.04	0.002*
Handgrip strength neutral position DH			
Change across assessments	0.00	0.03	0.985
Baseline group differences	−0.23	0.55	0.670
Change by group	0.26	0.04	< 0.001*
Handgrip strength neutral position NDH			
Change across assessments	−0.01	0.02	0.601
Baseline group differences	0.01	0.49	0.984
Change by group	0.23	0.03	< 0.001*
Handgrip strength supine position DH			
Change across assessments	0.02	0.02	0.309
Baseline group differences	−0.67	0.49	0.170
Change by group	0.15	0.03	< 0.001*
Handgrip strength supine position NDH			
Change across assessments	0.00	0.01	0.746
Baseline group differences	−0.05	0.52	0.931
Change by group	0.13	0.02	< 0.001*

Notes. Estimate = unstandardized regression coefficient; SE = standard error of measurement; DH = dominant hand; NDH = non-dominant hand. *Statistically significant after Holm-Bonferroni correction for multiple comparisons.

panied with considerable functional loss, especially in forward elevation of the arm [19]. Here, we present an exercise protocol focusing primarily on quality of global, stabilizing pattern (optimal trunk stabilization including shoulder girdle muscles coordination) as a prerequisite of an optimal extremity movement pattern that led to significantly increased hand strength. Figure 8, depicts the principle of differentiation between optimal (Fig. 8A) and abnormal (Fig. 8B) pattern of trunk stabilization in quadruped posture. Ideally, as shown on Figure 8A both hands provide support while maintaining functionally centrated position; i.e., the thenar and hypothenar areas are equally loaded, fingers are extended rather than hyperextended or flexed, both hands are "grasping" the floor providing support. Shoulder blades are in a neutral position, adhering to the rib cage, medial borders nearly parallel to the spine. The spine elongates, thoracolumbar junction is firm and stable, and proportionate activation of the muscles of the abdominal wall occurs.

Under pathological conditions (Fig. 8B), a decentration of the hands occurs. Usually, the hypothenar area is bearing more weight while the thenar section loses contact with the table. As a result, flexion at the elbow occurs. Often, the scapula on the ipsilateral slide loses its neutral position and is pulled cranially, while the lower angle rotates externally and the medial border protrudes. A collapse at the thoracolumbar junction is often related to an anterior pelvic tilt. Similar comparisons can be used in functional postural assessment in other positions (e.g. prone, side-sitting, bear position used in this study).

According to Richards et al. [4] the strongest forearm position for handgrip appears to be supination. However, our results indicated the strongest effects of DNS-based training occurred in the neutral position. An important aspect to consider may be the testing posture. Some authors use supine posture [21] while the standardized testing posture is considered to be sitting with shoulder adducted and neutrally rotated, with elbow flexed to 90 degrees [13]. But even this "standardized" posture is not clearly defined. It describes shoulder and elbow angles but not, for example, pelvic, spinal and chest position. Trunk muscles provide fixation for shoulder girdle muscles, which, in turn, allow for coordinated activity of forearm muscles, ensuring elbow stabilization [22] that influences handgrip strength. In this global kinetic chain, trunk muscle coordination and trunk segments positions may play an important role. In our study we used sitting position with chest, spine and pelvis in a neutral position as defined by the developmental models within the DNS paradigm [10,11] (Fig. 1).



A B

Fig. 8. Depicts the principle of differentiation between optimal (A) and abnormal (B) pattern of stabilization. (A:) Ideally, both hands provide support while maintaining functionally centrated position; i.e., the thenar and hypothenar areas are equally loaded, fingers are "freely" extended rather than hyperextended or flexed, both hands are "grasping" the floor providing support. Shoulder blades are in a neutral position, adhering to the rib cage, medial borders nearly parallel to the spine. The spine elongates, thoracolumbar junction is firm and stable, proportionate activation of the muscles of the abdominal wall occurs. (B:) Under pathological conditions, a decentration of the hands occurs. Usually, the hypothenar area is weight bearing more while the thenar section loses contact with the table. As a result, flexion at the elbow occurs. Often, the scapula on the ipsilateral slide loses its neutral position; it is pulled cranially, its lower angle rotating externally and the medial border protruding. A collapse at the thoracolumbar junction is often related to an anterior pelvic tilt. The same principles apply to all positions used in this study.

Our results build on previous research suggesting the importance of global stabilization stereotypes on hand muscle strength. Dash [23] observed improvement in handgrip strength after yoga training. Thomas et al. [9] instructed 15 healthy subjects to perform general resistance training for upper extremities three times a week for eight weeks. Compared to the control group, the training group showed significantly higher handgrip strength after eight weeks of training, but only for the right (dominant) hand.

Similar to our study, Thomas et al. [9] instructed the participants to exercise in positions demanding on shoulder stabilization (i.e. push-ups with hand and forearm support and dips in the supine position with hand support). However, Thomas et al. [9] did not put emphasis specifically on the precise positing of the shoulder, the scapula, or other supporting segments (elbows, hands) position, or on load distribution across weight bearing segments.

The uniqueness of our study over previous research lies mainly in a novel definition of functional joint centration and shoulder girdle muscle coordination from a developmental perspective. In addition, we present practical utilization of functional norms defined by developmental postural-locomotion patterns and positions resulting from genetically determined central nervous program [24]. Postural stability is a prerequisite for movement. It involves the entire musculoskeletal system, through an arrangement of regional interdependence and precise coordination (feed-forward mechanism) of muscles stabilizing a trunk. Therefore, achieving optimal trunk stabilization should be the first step when training optimal movement or strength.

There are several limitations to this study. First, the study was not blinded. Second, the control group participants had overall lower body mass index than the training group participants. However, this difference was controlled by including BMI in all models as a covariate. Third, the exercises were specifically chosen not to train handgrip strength, but in two positions (quadruped and bear position) the hands served as supporting segments and therefore hand muscle strength possibly also increased as a result of this loading. This aspect is also discussed in a study by Thomas [9]. They used both hands supported in two of three training positions and after the eight weeks of exercises identified significant increase in hand strength but only on the right (dominant) side. However, in this case, we would like to emphasize the importance of proportional loading of the palms when serving a supporting function and the importance of inter-linked functional centration between hand, wrist, elbow and shoulder girdle joints. Fourth, we used Citec dynamometer that was at our disposal to measure hand strength. The more generally used Jamar hand held dynamometer would allow for better comparison between our data and established norms [13], but this was not the primary goal of the presented study. Finally, we used a relatively small sample size in this pilot study. Larger, blinded experiments that include both no-contact and active control groups are necessary to ascertain the utility of DNS-based shoulder exercises in this context. Still, even results with this small sample were robust enough to remain significant after correction for multiple comparisons. Perhaps excluding positions requiring direct hand support from the exercise protocol may be useful to increase internal validity.

5. Conclusion

We found consistent gains in pinch grip strength and handgrip strength over the course of the study, pointing to the utility of DNS in improving proximal shoulder girdle stability. This study provides evidence for the critical importance of the quality of global trunk stabilizing pattern on distal extremity movement and strength.

Acknowledgements

This study was supported by the foundation Movement without Help, Prague, Czech Republic and Rehabilitation Prague School.

Conflict of interest

There are no conflicts of interest for any of the authors.

Statement of institutional review board approval of the study protocol

This study was approved by the Second Medical Faculty, Charles University and University Hospital Motol, Prague, Czech Republic, ethical committee.

References

[1] Farooq M, Khan AA. Effect of shoulder rotation, upper arm rotation and elbow flexion in a repetitive gripping task. Work. 2012;43:263-78. doi: 10.3233/WOR-2012-1391.
[2] Hillman TE, Nunes QM, Hornby ST, Stanga Z, Neal KR, Rowlands BJ,et al. A practical posture for hand grip dynamometry in the clinical setting. Clin Nutr. 2005;24:224-8. doi: 10.1016/j.clnu.2004.09.013.
[3] Oxford KL. Elbow positioning for maximum grip performance. J Hand Ther. 2000;13:33-6. doi: 10.1016/S0894-1130(00)80050-2.
[4] Richards LG, Olson B, Palmiter-Thomas P. How forearm position affects grip strength. Am J Occup Ther. 1996 Feb;50(2):133-8. doi: 10.1016/S0003-9993(97)90143-X.
[5] Kattel BP, Fredericks TK, Fernandez JE, Lee DC. The effect of upper-extremity posture on maximum grip strength. Int J Ind Ergon. 1996;18:423-9. doi: 10.1016/0169-8141(95)00105-0.
[6] Kuzala EA, Vargo MC. The relationship between elbow position and grip strength. Am J Occup Ther. 1992;46:509-12. doi: 10.5014/ajot.46.6.509.
[7] Nascimento LR1, Polese JC, Faria CD, Teixeira-Salmela LF. Isometric hand grip strength correlated with isokinetic data of the shoulder stabilizers in individuals with chronic stroke. J Bodyw Mov Ther. 2012 Jul;16(3):275-80. doi: 10.1016/j.jbmt.2012.01.002.
[8] Alexander CM, Miley R, Harrison PJ. Functional modulation of shoulder girdle stability. Exp Brain Res. 2005;161:417-22. doi: 10.1007/s00221-004-2083-y.
[9] Thomas EM, Sahlberg M, Svantesson U. The effect of resistance training on handgrip strength in young adults. Isokinet Exerc Sci. 2008;16:125-31.
[10] Kobesova A, Valouchova P, Kolar P. Dynamic Neuromuscular Stabilization: Exercises based on developmental kinesiology models. In: Liebenson ed. Functional Training Handbook. Philadelphia: Wolters & Kluwer; 2014. p. 25-51.
[11] Frank C, Kobesova A, Kolar P. Dynamic neuromuscular stabilization & sports rehabilitation. Int J Sports Phys Ther. 2013;8:62-73.
[12] Oppelt M, Juehring D, Sorgenfrey G, Harvey PJ, Larkin-Thier SM. A case study utilizing spinal manipulation and dynamic neuromuscular stabilization care to enhance function of a post cerebrovascular accident patient. J Bodyw Mov Ther. 2014 Jan;18(1):17-22. doi: 10.1016/j.jbmt.2013.04.003.

[13] Mathiowetz V, Kashman N, Volland G, Weber K, Dowe M, Rogers S. Grip and pinch strength: normative data for adults. Arch Phys Med Rehabil. 1985;66:69-74.
[14] Littell RC, Milliken GA, Stroup WW, Wolfinger RD, Schabenberger O. SAS for Mixed Models. 2nd ed. Cary N.C: SAS Press; 2006.
[15] Brown H, Prescott R. Applied mixed models in science. New York: Wiley; 1999.
[16] Gueorguieva R, Krystal JH. Move over ANOVA: progress in analyzing repeated-measures data and its reflection in papers published in the Archives of General Psychiatry. Arch Gen Psychiatry. 2004;61:310-7. doi:10.1001/archpsyc.61.3.310.
[17] Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics* 6 (2): 65-70.
[18] Sisto SA, Dyson-Hudson T. Dynamometry testing in spinal cord injury. J Rehabil Res Dev. 2007;44(1):123-36. doi: 10.1682/JRRD.2005.11.0172.
[19] Veeger HE, van der Helm FC. Shoulder function: the perfect compromise between mobility and stability. J Biomech. 2007;40(10):2119-29. doi:10.1016/j.jbiomech.2006.10.016.
[20] Meininger AK, Figuerres BF, Goldberg BA. Scapular winging: an update. J Am Acad Orthop Surg. 2011;19:453-62.
[21] Bohannon RW, Andrews AW. Interrater reliability of handheld dynamometry. Phys Ther. 1987;67:931-3.
[22] Richards LG. Posture effects on grip strength. Arch Phys Med Rehabil. 1997 Oct;78(10):1154-6. doi:10.1016/S0003-9993(97)90143-X.
[23] Dash M, Telles S. Improvement in hand grip strength in normal volunteers and rheumatoid arthritis patients following yoga training. Indian J Physiol Pharmacol. 2001;45:355-60.
[24] Kobesova, A., Kolar, P., Developmental kinesiology: Three levels of motor control in the assessment and treatment of the motor system. J Bodyw Mov Ther. 2014;18:23-33. doi: 10.1016/j.jbmt.2013.04.002.