

STUDY PROTOCOL

Official Title of the Study:

Acute Effects of Static Stretching, Assisted Dynamic Stretching, Kinesio Taping, Cold Water Immersion and Foam Rolling on Maximal Isometric Wrist-Flexion Strength and on Precise Force and Position Modulation of the Wrist in Healthy Adults: A Randomised Five-Period Crossover Trial

ClinicalTrials.gov Identifier (NCT number): not yet assigned (record released for PRS review, October 2026)

Organization's Unique Protocol ID: KIF-5/2022-Kovacic

Sponsor: University of Zagreb, Faculty of Kinesiology

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Document Version: 1.0

Document Date: 28 September 2026

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Protocol version 1.0 (retrospective compilation), 28 September 2026. ClinicalTrials.gov identifier: NCT [to be assigned]. Principal investigator: Grgur Kovačić, mag. cin., Faculty of Kinesiology, University of Zagreb (doctoral candidate); PROPRIO Centar – Physical Therapy, Zadar, Croatia; grgur.kovacic@student.kif.hr. Supervisor / scientific contact: Assoc. Prof. Tatjana Trošt, PhD, Faculty of Kinesiology, University of Zagreb; tatjana.trost@kif.unizg.hr. Sponsor: University of Zagreb, Faculty of Kinesiology (doctoral research project). Funding: none (investigator-initiated).

Statement on the nature of this document

This protocol was compiled after the study's completion for retrospective registration. It is based on the doctoral research proposal (University of Zagreb form DR.SC.-01) in the version approved by the Faculty of Kinesiology and the Senate of the University of Zagreb (decision of 17 January 2023), the report of the evaluation committee (form DR.SC.-02) from the public defence of the topic on 14 February 2019, and the study as conducted between 4 April and 13 May 2022, as reported in the doctoral dissertation. Sections 3–11 describe the study as conducted; Section 12 lists the history of the protocol and every difference between the approved proposal and the conducted study that the investigators could identify.

1. Background and rationale

Static stretching, dynamic stretching, elastic (Kinesio) taping, brief cold water immersion and foam rolling are applied daily in sport preparation and rehabilitation of the forearm and hand with the expectation of facilitating or, for cooling and static stretching, impairing neuromuscular function. The evidence comes almost entirely from large lower-limb muscle groups; for the wrist flexors, no study compared these methods in the same participants, and the tasks measuring precise control of force and joint position at the wrist had unknown measurement properties. The doctoral project therefore measured the acute effect of all five methods on three dimensions of wrist neuromuscular function—maximal isometric strength, precise modulation of submaximal force, and precise modulation of joint position—in the same healthy adults.

2. Objectives and hypotheses

Primary objective: to determine the acute effect of each of the five interventions on (a) peak isometric wrist-flexion force, (b) the normalised error of a force-tracking task and (c) the normalised error of a position-tracking task. Secondary objectives: to compare the interventions with one another; to separate the effect of an intervention from the effect of repeated performance of the tasks (motor learning); to establish the measurement properties (reliability, standard error of measurement, minimal detectable change) of all variables; to examine sex differences; to examine the association between the three dimensions.

Hypotheses as stated in the approved proposal and in the dissertation (see Section 12): H1 – assisted dynamic stretching, Kinesio taping and foam rolling produce a statistically significant improvement in precise force modulation, precise position modulation and maximal wrist strength; H2 – cold water immersion and static stretching produce a statistically significant impairment of the same three outcomes. Two research questions were formulated during the analysis and are labelled post hoc in all reports: P1 – does tracking performance change systematically across visits independently of the intervention, and how much of the within-visit change is attributable to repeated performance; P2 – does the active range of palmar flexion change after the interventions.

3. Design

Single-centre, randomised, five-period crossover trial in which every participant received all five interventions, one per weekly visit, in an individually randomised order; open (no masking of participants or examiner); measurements immediately before and after each intervention. Six visits in total: familiarisation and baseline measurement (visit 0) and five intervention visits (visits 1–5).

4. Setting

PROPRIO Centar – Physical Therapy, Ante Starčevića 7A, 23000 Zadar, Croatia (physiotherapy centre with a laboratory room); all measurements on one HAMOCODI system (S2P Ltd., Ljubljana, Slovenia).

5. Participants

Inclusion: healthy adults recruited through a public call on the social-media pages of the centre; right-hand dominant (throwing hand); written informed consent. Exclusion: left-hand dominance; current pain in the dominant arm or a history of injury limiting its function or range of motion (structured interview following the Michigan Hand Outcomes Questionnaire); diagnosed neuromuscular disorder; participation in competitive sport; joint hypermobility on the Beighton scale. Recruitment and consent: applicants received the study plan, exclusion criteria, obligations and possible risks by e-mail; the same content was explained orally at the introductory meeting, after which participants signed the consent form. Planned sample: 50 (the a priori calculation was not retained). Enrolled: 58 attended the introductory meeting; one man was excluded because of forearm pain during the strength test at familiarization, and one woman withdrew after the baseline visit because of illness; 56 participants (29 men, 27 women; age 22–36 years) were randomised and analysed; four missed one intervention visit for unrelated reasons and were retained.

6. Interventions

All interventions were applied to the flexor muscles of the right forearm by the same examiner with scripted instructions, once per visit, between the pre- and post-intervention measurement blocks; dose 60 s each. (a) Static stretching: self-administered stretch of the wrist and finger flexors with the elbow extended and forearm supinated, one continuous bout of 60 s to the limit of pain tolerance. (b) Assisted dynamic stretching: active elbow and wrist extension, passive assistance of finger and wrist extension by the other hand at the end of the range to the limit of pain tolerance, hold ≈ 2 s, active return ≈ 2 s; ≈ 15 cycles in 60 s, non-ballistic. (c) Kinesio taping (Kinesio Tex Gold, 5 cm): facilitation Y-strip

from the medial epicondyle along the wrist flexors at 30–40% tension plus an I-strip across the palmar wrist at 50–75% tension with inward pressure, per the method manual; tape kept on during the post-intervention measurement. (d) Cold water immersion: hand and forearm immersed above the elbow in water at 14 ± 1 °C for 60 s. (e) Foam rolling: forearm flexors rolled on a smooth foam roller for 60 s, pressure to the limit of pain. Full TIDieR descriptions are given in the registry record.

7. Outcomes

All outcomes were measured on the HAMOCODI system (dynamometric module: Forsentek FL25 load cell; goniometric module: RLS RM08I encoder; sampling 1000 Hz; 5-ms moving average). Primary outcomes, measured immediately before and after every intervention and at baseline: (1) peak isometric wrist-flexion force (N), highest 1-s moving average in the best of three maximal contractions of 3–5 s; (2) normalised error of the force-tracking task (%), root-mean-square deviation of the produced force from a randomly generated sinusoidal reference curve (0–70% of the peak force measured immediately beforehand; 40.2 s; three trials, mean used) divided by the reference amplitude; (3) normalised error of the position-tracking task (%), the same measure for the wrist angle with the reference curve scaled to 65% of the active range of motion measured immediately beforehand. Secondary outcomes: active palmar-flexion range of motion (°); change of tracking error across the pre-intervention measurements of consecutive visits (learning); the further variables exported by the software (mean absolute error and the remaining thirteen of sixteen variables); change in peak force by repetition position; reliability, standard error of measurement and minimal detectable change of all variables; dispersion of individual responses; sex differences. Order of the tasks in every block: peak force, force tracking, range of motion, position tracking.

8. Participant timeline

Visit	Content
0 (week 1)	Introductory meeting and consent; screening; familiarisation with the device and tasks; 30-min rest; baseline measurement block
1–5 (weeks 2–6, same weekday and time of day)	Pre-intervention block ($\approx$ 11–12 min) → intervention (60 s; taping longer) → post-intervention block, starting 10–20 s after the intervention
Washout	$\geq$ 6 days between visits (median 7 days)

9. Sample size

The proposal planned 50 participants (25 men, 25 women); the documentation of the a priori calculation was not retained. With the 56 participants analysed, a paired standardised difference of $dz \approx 0.38$ ($\approx$ 3% of peak force) is detectable with $\alpha = 0.05$ and 80% power (sensitivity analysis).

10. Randomisation, allocation concealment and blinding

Simple randomisation without blocking, performed once before the first measurement: for each participant code a person not involved in testing generated a random permutation of the numbers 1–5 (Random.org), each number denoting one intervention. The list was held by that person; the examiner learned the intervention only on the day of the visit. Neither participants nor the examiner could be blinded to the intervention during the visit; the measurement system recorded outcomes automatically. Because blocking was not used, the distribution of interventions across visit positions was not perfectly

balanced (e.g., cold water immersion first for 18 participants, fourth for 7), so visit order is a covariate in the analysis.

11. Data collection, management and monitoring

The same examiner made all measurements with an assistant. The acquisition software (ARS 2.1.0.11) stored raw signals and derived variables with timestamps; peak force was verified by reconstructing it from the raw signals. Data were exported to spreadsheets, checked for completeness and analysed with jamovi and Python. No interim analyses, data monitoring committee or stopping rules were foreseen (low-risk physical interventions in healthy adults; one-session exposure). Adverse events: none beyond transient discomfort inherent in stretching to the limit of pain tolerance and cold exposure; one participant was excluded at familiarisation because of forearm pain during the strength test.

12. Development of the protocol and differences between the approved proposal and the conducted study

History. (1) 14 February 2019: public defence of the original proposal ("Modulacija kontrole pokreta u ciljanim zglobovima šake pod utjecajem vanjskih čimbenika"), which foresaw a broader battery (wrist flexors and extensors and a pinch-grip task), ballistic instead of dynamic stretching, a 7-min cooling protocol with skin-temperature control, repeat tests 5 min after each intervention, a fixed order of interventions and a sample aged 20–25. The evaluation committee recommended changing the title, randomising the order of visits, separating the person who randomises from the examiner, adding right-hand dominance as an exclusion criterion, conducting weekly visits, standardising the subjective pain limit, describing the temperature control of cold water immersion, and reconsidering the statistical method. (2) The proposal was revised accordingly by the investigators: the battery was reduced to the wrist flexors (the original battery with five interventions was judged too extensive), ballistic stretching was replaced by dynamic stretching as the form used in practice and applicable to the forearm, cooling was set to 60 s at 14 °C, the order of interventions was randomised, and the hypotheses were formulated as H1 and H2 above. (3) March 2022: pilot check with five volunteers (including the principal investigator), none of whom took part in the main study, used to finalise the execution of the interventions and the timing of the measurement blocks (see table). (4) 14–18 February 2022: approval of the Committee for Scientific Research and Ethics (No. 5/2022). (5) 4 April – 13 May 2022: data collection. (6) 17 January 2023: Senate decision approving the topic. The revised proposal describes the study as conducted, with the differences listed below.

Element	Approved proposal (DR.SC.-01)	Study as conducted (2022)	Reason / origin of the change
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Sample	50 (25 men, 25 women), aged 20–35, right-hand dominant, non-athletes	58 screened, 56 analysed (29 men, 27 women), aged 22–36	Good response to the public call: all volunteers who met the criteria were enrolled, without selection. The upper age limit of 35 was a pragmatic recruitment criterion; one eligible volunteer aged 36 was included by the investigators' decision before enrolment. Population changed from students in Zagreb (original 2019 plan) to the general population in Zadar because the principal investigator relocated; all other criteria applied as written.
Reference amplitude of the tracking curves	Force: 10–70% of MVC; position: 10–90% of the range of motion	Force: 0–70% of peak force; position: 65% of the active range of motion, centred (19.7–84.8% of ROM)	Settings of the HAMOCODI software: a lower limit of the force range and a 10–90% position range cannot be set.
Assisted dynamic stretching: execution and tempo	Other hand places fingers and wrist in end-range extension, then elbow extension; 20 cycles/min set by a metronome	Active elbow and wrist extension, passive assistance of finger and wrist extension by the other hand at the end of the range; ≈ 15 cycles/min (≈ 2 s hold, ≈ 2 s return), tempo demonstrated, no metronome	Pilot check (March 2022): this execution was the most practical and the closest to how the wrist flexors are stretched dynamically in practice; the metronome was omitted so that attention was not diverted from the stretch to the rhythm.
Foam rolling: tempo	20 rolls/min set by a metronome, 60 s	60 s at a self-selected tempo, with pauses on tender spots; no metronome	Pilot check (March 2022): pausing on tender spots is how the method is applied in practice and is incompatible with a fixed metronome tempo.
Timing within a visit	2-min pause between tests; 10-min pause between the pre-intervention block and the intervention	Tasks followed one another with ≈ 2 min between them; no separate 10-min pause (the intervention began ≈ 12 min after the pre-intervention strength test because the two tracking tasks intervened)	Pilot check (March 2022): the block was not fatiguing and all volunteers felt ready to continue; a 10-min wait would only have reduced concentration. In the main study the tracking tasks themselves separated the strength test from the intervention by ≈ 12 min.
Statistical analysis	Statistica 13.3; repeated-measures ANOVA for the change within each condition; Dunnett's test between conditions	Log-ratio changes; linear mixed models with intervention, visit order and sex; Holm correction; equivalence tests; reliability analyses (see SAP)	Specified during the analysis (2026): the baseline could not serve as a control because tracking performance improved systematically across visits; mixed models accommodate the four missing visits.

13. Ethics and dissemination

The study formed part of a doctoral research project whose topic was publicly defended and evaluated at the Faculty of Kinesiology, University of Zagreb, in February 2019. The Committee for Scientific Research and Ethics of the Faculty of Kinesiology approved the study (No. 5/2022) on 18 February 2022, and data were collected from 4 April to 13 May 2022. The study was conducted in accordance with the Declaration of Helsinki; all participants gave written informed consent before participation. Results are disseminated in the doctoral dissertation (University of Zagreb, 2026) and in manuscripts submitted to peer-reviewed journals. The anonymised trial-level dataset, data dictionary and analysis files are openly available (CC BY 4.0) in the Dabar repository: <https://urn.nsk.hr/urn:nbn:hr:117:012259>.