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Does a counterforce brace reduce common extensor tendon loading during a wrist extension task? An in vivo study

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ABSTRACT

This study assessed the biomechanical effect of a counterforce brace on the common extensor origin (CEO) tendon at the elbow via the measurement of shear wave velocity (SWV) using ultrasound. The counterforce brace was hypothesised to reduce SWV, which is a proxy measure of tendon stiffness, whilst the wrist and finger extensors were contracting at different levels of maximum voluntary contraction (MVC). In this cross-sectional study, nineteen healthy participants (age±SD: 30±9) were included in the study. The counterforce brace was applied with either 0 or 80 mmHg pressure to the forearm. The SWV was measured under four different wrist extensors MVC levels: 0%, 20%, 30%, and 40%. The counterforce brace had no significant effect on CEO tendon SWV at rest (V-statistic = 86, p = 0.74), 20% (V-statistic = 105, p = 0.71), 30% (V-statistic = 87, p = 0.77), or 40% (V-statistic = 94, p = 0.98) of MVC. The Friedman test for repeated measures showed an increase in SWV with greater levels of wrist extension MVC ($x^2 = 7.9$, p = 0.048). In conclusion, the counterforce brace does not appear to have a biomechanical effect on the CEO of the elbow during resting conditions or whilst the wrist extensors are contracting. The SWV of the CEO, a proxy for tendon stiffness, increases with greater levels of MVC.

1. Introduction

Symptomatic common extensor origin (CEO) tendinopathy, commonly known as tennis elbow, affects 1–3% of the population each year and leads to millions of dollars of direct and indirect health costs worldwide (Ikonen et al., 2022). This condition impairs individuals' ability to perform gripping and manual tasks due to the severe pain often associated with it.

Several therapeutic interventions have been suggested to manage this condition and a counterforce brace is often prescribed as a therapeutic adjunct (Bateman et al., 2021). Cadaver studies have shown that by applying a counterforce brace to the proximal forearm, the strain on the CEO is reduced compared to no brace (Meyer et al., 2003; Takasaki et al., 2008). These findings are thought to be due to compressive forces generated by the brace increasing friction in areas more distal to the CEO which reduce strain on the CEO tendon (Harding III, 1992). Despite this theory, friction has also the potential to increase strain on the CEO due to the tension caused by the brace on the distal aspect of the musculotendinous junction.

No study to date has assessed the biomechanical effect of a counterforce brace in vivo. Shear wave elastography is a non-invasive method that can be utilised to measure tissue stiffness by assessing the shear wave velocity (SWV) propagation in the tissue of interest (Creze et al., 2018). While this measurement is a proxy for tissue stiffness

Abbreviations: CEO, Common extensor origin; SWV, Share wave velocity; MVC, Maximum voluntary contraction; mmHg, Millimetres of Mercury; MHz, Mega Hertz; ICC, Intraclass correlation coefficient; SEM, Standard error of the measurement; MDC, Minimal detectable change; CI, Confidence interval; LCA, Latent class analysis; BMI, Body mass index.

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(Andrade et al., 2022), the validity and reliability for the measurement of muscle and tendon stiffness was demonstrated in healthy individuals as well as participants with muscle/tendon pathology, such as the CEO (Coombes et al., 2018; Zhu et al., 2020). Since the stiffness is closely related to the load or stress, measurement of SWV could provide indirect evidence of the effect of a counterforce brace on CEO load during muscle contractions of the finger and wrist extensors (Hug et al., 2015).

Counterforce braces vary by design, however, those providing a forearm compression estimate allow a more accurate assessment of loads being applied to structures encompassed by the brace (Meyer et al., 2003). Different compression levels varying between 20–100 mmHg have been utilised in clinical settings and research. It appears that higher levels of pressure (e.g., 200 mmHg) provide greater pain relief in people with CEO tendinopathy (Meyer et al., 2003; Ng & Chan, 2004). However at pressures greater than 150 mmHg, the reduction in strain on the CEO is marginal (Takasaki et al., 2008). Of note, there has been no consistent evidence for utilising a particular compression level in CEO tendinopathy. In addition, there are no studies that have examined the effects of compression on mechanical properties (e.g., stress, strain, stiffness) at the CEO when muscles attached to it are working at different levels of activation. It would seem logical to choose levels of muscle activity that are observed in common physical tasks. During low (15% of MVC) to moderate (60% of MVC) gripping tasks, the wrist and fingers extensors have been shown to work to a maximum of 40–50% of their MVC (Forman et al., 2021) and pain-free wrist extension levels in people with CEO tendinopathy have been shown to reach 62.7 N (SD 29.1), which equated to 47% of the unaffected side (Coombes et al., 2016). The wrist and finger extensors are active during gripping to counteract the flexion moment generated by the finger flexors at the wrist (Forman et al., 2021). Furthermore, individuals with CEO tendinopathy often present with functional activity limitations due to pain during low to moderate levels of upper limb loading (e.g. 20–40% of pain-free grip strength) (Cooke et al., 2021). This is reflected by research that has been assessing motor control features at grip strength levels of 15% to 30% of MVC in people with CEO tendinopathy (Manickaraj et al., 2018).

To date, no in-vivo studies have assessed the effect of different levels of muscle activation on tissue stiffness at the CEO when wearing a counterforce brace. It is of interest to assess the effectiveness of a counterforce brace applied at 80 mmHg of pressure under four different conditions, namely: 0%, 20%, 30%, and 40% of wrist and finger extensors MVC. It was hypothesised that the counterforce brace inflated to 80 mmHg would reduce CEO stiffness when applied to the 20%, 30%, and 40% contraction levels compared to the same MVC levels without pressure. In addition, we expected that CEO stiffness would increase with higher levels of MVC.

2. Methods

This was a cross-sectional study assessing healthy participants during a single testing session. The study was conducted at Auckland University of Technology and was approved by the AUTEC ethics committee (20/250), in accordance with the principles set out in the declaration of Helsinki. The STROBE checklist for cross-sectional studies has been reported as an appendix.

2.1. Participants

Healthy participants were included if they were between 18 and 65 years old and presented with no history of pain in the right upper limb. Exclusion criteria included being diagnosed with CEO tendinopathy in the past, inability to lie supine, limited range of movement in shoulder internal rotation/elbow extension of the right upper limb, or inability to communicate in English. Demographic data were collected prior to testing. All participants provided written informed consent for the experimental procedure.

2.2. Testing position and tasks

Participants were asked to lie supine, and testing was completed on the right upper limb. The shoulder was positioned, through an analogue goniometer, in 40° of shoulder abduction, 70° internal rotation, the elbow was flexed to 30°, and the wrist was maintained in 0° of extension (Fig. 1). To maintain this position, a desk with a hard foam wedge was placed next to the plinth on their right side. Above the wedge, a wooden structure with a horizontal portal allowed the insertion of rigid strap. The rigid webbing was wrapped around the distal aspect of the second to fifth metacarpal bones just proximal to the metacarpophalangeal joints. This was done to resist wrist extension (isometric contraction) whilst keeping the fingers extended. The strap was placed in series with a force gauge (Tension/Compression load cell, Model PST, 100 kg capacity, Precision Transducers Ltd), which was held in place by two weightlifting plates (40 kg total). The webbing and force gauge were perpendicular to the floor and at a 20° angle at the metacarpals. This position was maintained throughout testing (see Fig. 1).

An inflatable pressure cuff (infant size, bladder size 5.5 x 15 cm), resembling a circumferential forearm brace and secured through velcro, was then placed 5 cm distal to their lateral epicondyle. This placement was chosen based on previous evidence (Kroslak et al., 2019; Songur et al., 2024). A pressure sensor (MPS20N0040D-D) was connected to the pressure cuff system to monitor and record pressure during the testing sessions. The pressure system was adjusted based on a calibrated sphygmomanometer. For assessment of maximum wrist and finger extension strength, the force gauge (PT Limited; S shape precision strain transducer, 100 kg capacity) was connected to customised computer software produced in LabVIEW (LabVIEW software, Version: 2019, Austin, TX, USA). The pressure sensor was synchronised with the signal from the force gauge in LabVIEW to be able to have recordings of both force and pressure during testing. After familiarisation with the procedures including three submaximal practice trials, three MVCs of isometric wrist extension were recorded with 30 s rest between each trial. Participants were able to maintain the same force output by having real time feedback of the force output on a screen on their side. Verbal encouragement was given during the MVC trials (McNair et al., 1996). The highest MVC was used to calculate the 20%, 30%, and 40% level for the different testing conditions. A total of eight conditions were assessed: 0%, 20%, 30%, 40% MVC with 0 mmHg or 80 mmHg counterforce brace pressure. The 80 mmHg was chosen for the following reasons: this level of pressure has been shown to be the average pressure applied by patients in clinical practice when wearing a counterforce brace, this pressure level appears to reduce strain on the CEO by 15–25% in cadavers, and higher levels of pressure do not appear to further reduce CEO strain but make wearing the brace uncomfortable (Meyer et al., 2003; Takasaki et al., 2008). The isometric wrist extension exercise was chosen as this had been previously tested in research settings in people with symptomatic CEO tendinopathy (Coombes et al., 2016). The randomisation order of each condition and pressure was randomised for all participants. The randomisation order for both the MVC level and cuff pressure was created in a Microsoft ® Excel spreadsheet.

2.2.1. Shear wave velocity measurement

An AixPlorer ultrasonic scanner (Supersonic Imagine, Aix en Provence, France), coupled with a linear transducer array (4–15 MHz, SuperLinear 15–4, Vermon, Tours, France) was utilised to assess the SWV (m/s). Saturation level was set to 23 m/s, depth was modified to accommodate for anatomical differences and allow the visualisation of the lateral epicondyle, radial head and CEO tendon, and brightness was automatically adjusted. The ultrasound probe was maintained manually over the participant's CEO, proximal to the counterforce brace, and it was not moved for the entire testing session (Krogh et al., 2020). Bony landmarks utilised for the scanning included the lateral epicondyle and radial head. Based on the individual participant's MVC level, the force target level for each condition was projected on a computer screen on

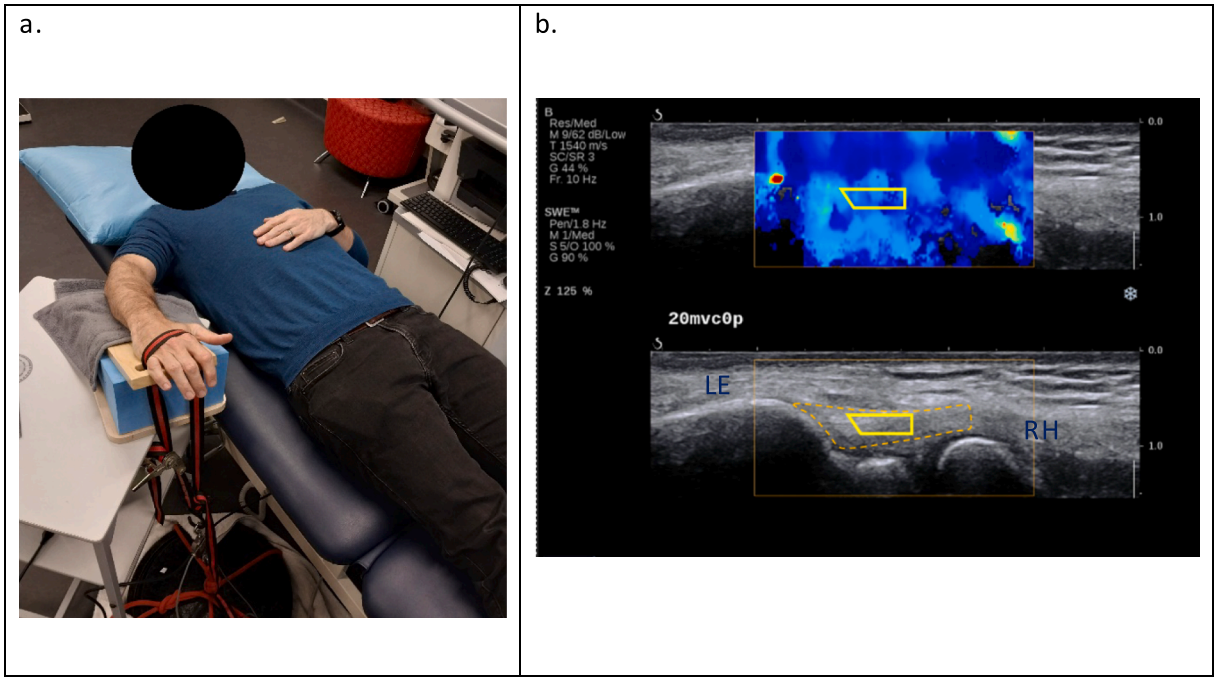

Fig. 1. Testing position (a) and example ultrasound image with SWV (b). In figure a, the strain gage was placed in series with the webbing connecting the hand to the weight on the floor. In figure b, the yellow trapezoid shape was the area utilised to calculate SWV. The dashed orange line in the B-mode of the ultrasound image represents the common extensor origin tendon. The lateral epicondyle (LE) and the radial head (RH) are identified on the picture. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the left side of the participant. Participants were asked to maintain the force at the target level for seven seconds during which five seconds of ultrasound SWV were recorded. Each condition was recorded three times (total of 24 video clips) with 30 s to rest between each measurement.

2.2.2. Data processing

Each video clip was processed individually through MatLab (R2023b). The region of interest within the CEO (middle 50% of the length of each participant's tendon) was identified and manually outlined to use for data processing (Fig. 1-b). The placement of the ROI was selected to gain information from the largest portion of the tendon and this approach has been implemented in previous research on SWV of the CEO (Day & Merriman, 2024; Elsayed et al., 2022). The mean SWV (m/s), a proxy for tendon stiffness, was calculated across the whole duration of the video (5 s). The average of each video SWV was utilised to assess reliability across the three repeated measures. The average of three SWV video s for the same condition was utilised to assess the effect of %MVC levels and counterforce brace pressure change on SWV measurements. Percentage saturation and void were also reported for each condition. Percentage saturation refers to the proportion of area that reached the highest SWV recordable by the machine. When values are higher than this threshold, they are set to the saturation level. Percentage void refers to the amount of missing data from the area recorded through SWV, due to a low quality in the tracking of the shear wave. We tried to maintain saturation and void as low as possible. Levels of void and saturation below 5% were considered as acceptable.

2.3. Data analysis

A power calculation was performed to determine the sample size. A paired *t*-test with an a priori computation for sample size was utilised. The calculated effect size, based on tendon strain reduction through a counterforce brace inflated at two different pressure levels in cadavers, was 0.8. This was obtained by extracting the average and standard deviation reduction under the 100 mmHg (experimental) and 50 mmHg (control) conditions from Fig. 2 of Meyer et al. (2003). In particular, we estimated the experimental and control condition to reduce CEO load by 14% (SD ± 5%) and 10% (SD ± 4.5%) respectively. Using G*power 3.1.9.7 software (Faul et al., 2007) with an alpha level (p-value) of 0.05 and a power of 0.80, the sample size calculated, for a one-tailed hypothesis, was 12 participants. The sample size calculated for a two-tailed hypothesis was 14.

Data were analysed with R (4.2.2) in Rstudio (2023.06.2; Build 561). Categorical variables are expressed as frequencies, and continuous variables are expressed as mean and standard deviation if normally distributed, or median and interquartile range if not normally distributed. Intraclass correlation coefficients (ICC) for absolute agreement between measurements were utilised to assess intra-rater reliability of the SWV measure using the three trials under each of the eight conditions (0 mmHg at 0% of MVC, 80 mmHg at 0% of MVC, 0 mmHg at 20% of MVC, 80 mmHg at 20% of MVC, 0 mmHg at 30% of MVC, 80 mmHg at 30% of MVC, 0 mmHg at 40% of MVC, 80 mmHg at 40% of MVC). Measurement error and responsiveness of the tests were determined by calculating the standard error of the measurement (SEM) and the minimal detectable change (MDC_{95}: $1.96 \times \sqrt{2} \times SEM$) with a 95% confidence interval (95% CI) (Denegar & Ball, 1993). Wilcoxon signed-rank tests were completed to test the effect of cuff pressure of the counterforce brace (0 mmHg and 80 mmHg) across four different percentages of MVC (0%, 20%, 30%, and 40%). In addition, a Friedman test was completed to assess the effect of percentage MVC on SWV.

A secondary analysis was completed to assess whether there was a subgroup of participants who responded differently to the pressure delivered through the counterforce brace. In particular, a latent class analysis (LCA) was used to separate participants into two groups based on their SWV values across different MVC level (Dumenci et al., 2019). A model with random slopes forcing two classes was applied to participants whilst the pressure was on or off.

3. Results

A total of 19 healthy participants were recruited. Demographic and

descriptive characteristics are reported in Table 1.

3.1. SWV reliability

The SWV measurements appeared to have high reliability, with the lowest ICC being 0.94 and lowest lower bound 95%CI being 0.87. The largest MDC for the measurement was 1.37 m/s (See Table 2). The highest average saturation level was 0.6% and the highest average void was 3.6% (Table 3). The pressure recorded whilst the counterforce was inflated averaged 83 (SD:13) mmHg.

3.2. Effect of the counterforce brace and MVC on SWV

The counterforce brace had no significant effect on CEO tendon SWV under no muscle contraction (V-statistic = 86, p = 0.74), 20% (V-statistic = 105, p = 0.71), 30% (V-statistic = 87, p = 0.77), or 40% (V-statistic = 94, p = 0.98) of MVC (See Fig. 2). The Friedman test for repeated measures showed a statistically significant increase in SWV over the four MVC conditions (x^2 = 7.9, p = 0.048). The latent class analysis showed that a small subgroup of participants (26%) presented with a lower SWV when wearing the inflated counterforce brace (See Fig. 3 – a). The LCA did not identify obvious subgroups when assessing the no pressure condition (See Fig. 3 – b).

4. Discussion

This is the first in vivo study to assess the effect of a counterforce brace on the CEO tendon stiffness (as measured by SWV) during a loading wrist and finger extension task. In contrast to our hypothesis, the counterforce brace inflated to 80 mmHg had no effect on the SWV of the CEO compared to no pressure. In line with our prediction, CEO SWV increased with higher levels of MVC.

The observed SWV measurements that we obtained under no muscle contraction was 11–11.5 m/s (median) are similar to the values reported by other researchers when measuring SWV in healthy CEO tendons (Day & Merriman, 2024; Elsayed et al., 2022; Zhu et al., 2020). Equally, our measurements demonstrated high levels of reliability as shown by other groups (Day & Merriman, 2024; Elsayed et al., 2022; Zhu et al., 2020). Unfortunately, no previous study has assessed SWV under active contraction of the wrist or finger extensors and it is therefore not possible to make a direct comparison to other studies. The only study that assessed tendon SWV under no muscle contraction and during 10% of quadriceps contraction in healthy individuals (Bravo-Sánchez et al., 2022) showed a 16% increase in stiffness of the patellar tendon compared to a resting condition. This change in stiffness is greater than the change in SWV we identified in the CEO tendon during the transition from no contraction to 20% MVC, which was below 5% of baseline measurements (See Fig. 2). This finding may be attributed to biomechanical differences between the CEO and the patellar tendon. Unlike the patellar tendon, the CEO likely plays a greater role in energy transfer rather than in energy storage and release (Thorpe et al., 2015).

In contrast with evidence from cadaver studies (Meyer et al., 2003; Takasaki et al., 2008), we did not show that a counterforce brace reduced stiffness in the CEO. This may be explained by differences in loading on the CEO being generated by dynamic muscle activation in the current study rather than by passive tension applied to the distal aspect of the extensor tendon in cadavers. The counterforce friction theory suggested by Meyer et al. (2003) and Takasaki et al. (2008) is not supported by the findings of our study, and is therefore unlikely to be responsible for subjective improvements in pain during gripping tasks in people wearing a counterforce brace for CEO tendinopathy (Ng & Chan, 2004; Songur et al., 2024). It is therefore possible that other splinting approaches may be equally helpful in the management of people with CEO tendinopathy (Boccolari et al., 2024; Songur et al., 2024).

Table 1
Demographic and descriptive characteristics.

Variable	Mean (SD)/Frequency
Age (years)	30.1 (8.7)
Height (m)	1.7 (0.1)
Weight (kg)	76.8 (16.4)
BMI	25.7 (4.4)
Working status	
Full time	12
Part time	7
Unemployed	0
Retired	0
Type of work (Matheson et al., 1996)	
Sedentary	6
Light	7
Medium	3
Heavy	3
Very Heavy	0
Right hand dominant	15
Forearm circumference (cm)	28.3 (2.7)
MVC (kg)	15.3 (5)

Note. BMI, body mass index; MVC, maximum voluntary contraction

Table 2
SWV reliability measurements.

Variable	ICC	Lower Bound 95% CI	SEM (m/s)	MDC_{95} (m/s)
0% MVC & 0 mmHg	0.97	0.93	0.37	1.03
0% MVC & 80 mmHg	0.97	0.94	0.38	1.04
20% MVC & 0 mmHg	0.97	0.94	0.4	1.1
20% MVC & 80 mmHg	0.94	0.87	0.5	1.37
30% MVC & 0 mmHg	0.96	0.92	0.48	1.32
30% MVC & 80 mmHg	0.97	0.93	0.38	1.06
40% MVC & 0 mmHg	0.96	0.92	0.39	1.09
40% MVC & 80 mmHg	0.98	0.96	0.3	0.83

Note. ICC, Intraclass correlation coefficient; CI, Confidence Interval; SEM, standard error of the measurement; MDC_{95}, minimal detectable change; MVC, Maximum voluntary contraction; mmHg, millimetres of Mercury.

Table 3
SWV percentage saturation and void.

Variable	Saturation (SD) (%)	Void (SD) (%)
0% MVC & 0 mmHg	0.12 (0.53)	2.19 (2.30)
0% MVC & 80 mmHg	0.02 (0.09)	1.79 (1.98)
20% MVC & 0 mmHg	0.56 (2.33)	3.57 (2.23)
20% MVC & 80 mmHg	0.11 (2.33)	3.10 (2.36)
30% MVC & 0 mmHg	0.52 (1.45)	3.64 (2.95)
30% MVC & 80 mmHg	0.63 (1.86)	3.03 (3.29)
40% MVC & 0 mmHg	0.30 (0.82)	2.84 (3.14)
40% MVC & 80 mmHg	0.36 (0.93)	3.04 (2.36)

Note. MVC, Maximum voluntary contraction; mmHg, millimetres of Mercury; SD, standard deviation.

4.1. Study limitations

Our study presents with several limitations. First, SWV is a proxy in vivo measure for tissue stiffness and is therefore less precise than strain gauges that can be used only in vitro. However, the measurements obtained on the CEO tendon were reliable and, considering the MDC, we should have been able to detect a greater than 10% change in SWV. Second, we assessed the effect of a counterforce brace during a wrist and finger extension task only. This is not a functional activity. However, shear wave elastography can only be used in isometric conditions. In addition, we aimed to replicate the cadaver studies in-vivo and this was the procedure that most closely resembled previous biomechanical research. Third, we included a sample of healthy participants to allow an easier quantification of tendon SWV. Inclusion of people with

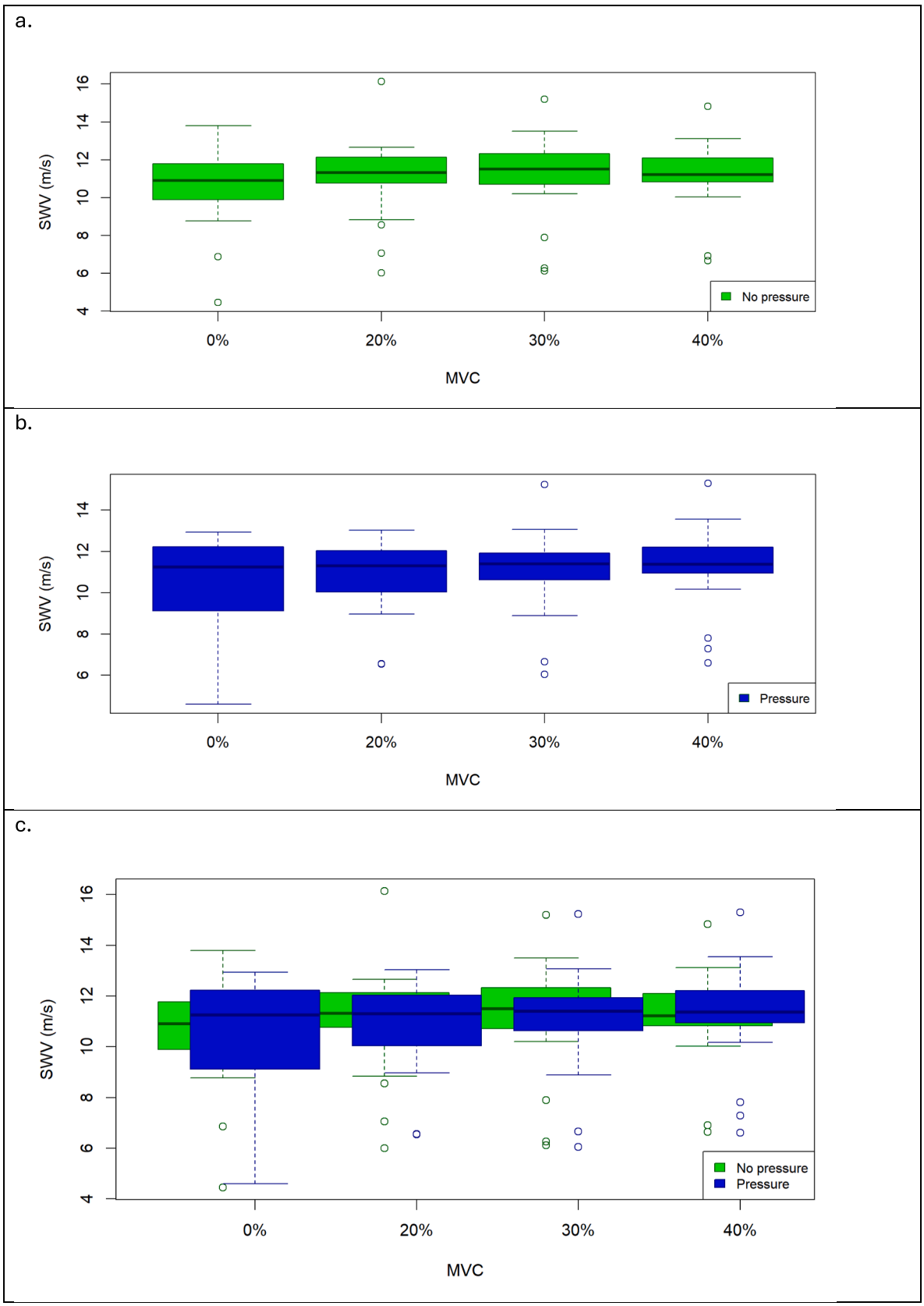

Fig. 2. Shear Wave Velocity (SWV) of the common extensor origin (CEO) tendon without (a) and with (b) a counterforce brace at different percentages of maximal voluntary contractions (MVC). Both conditions are reported in c. Data are reported as median and interquartile range.

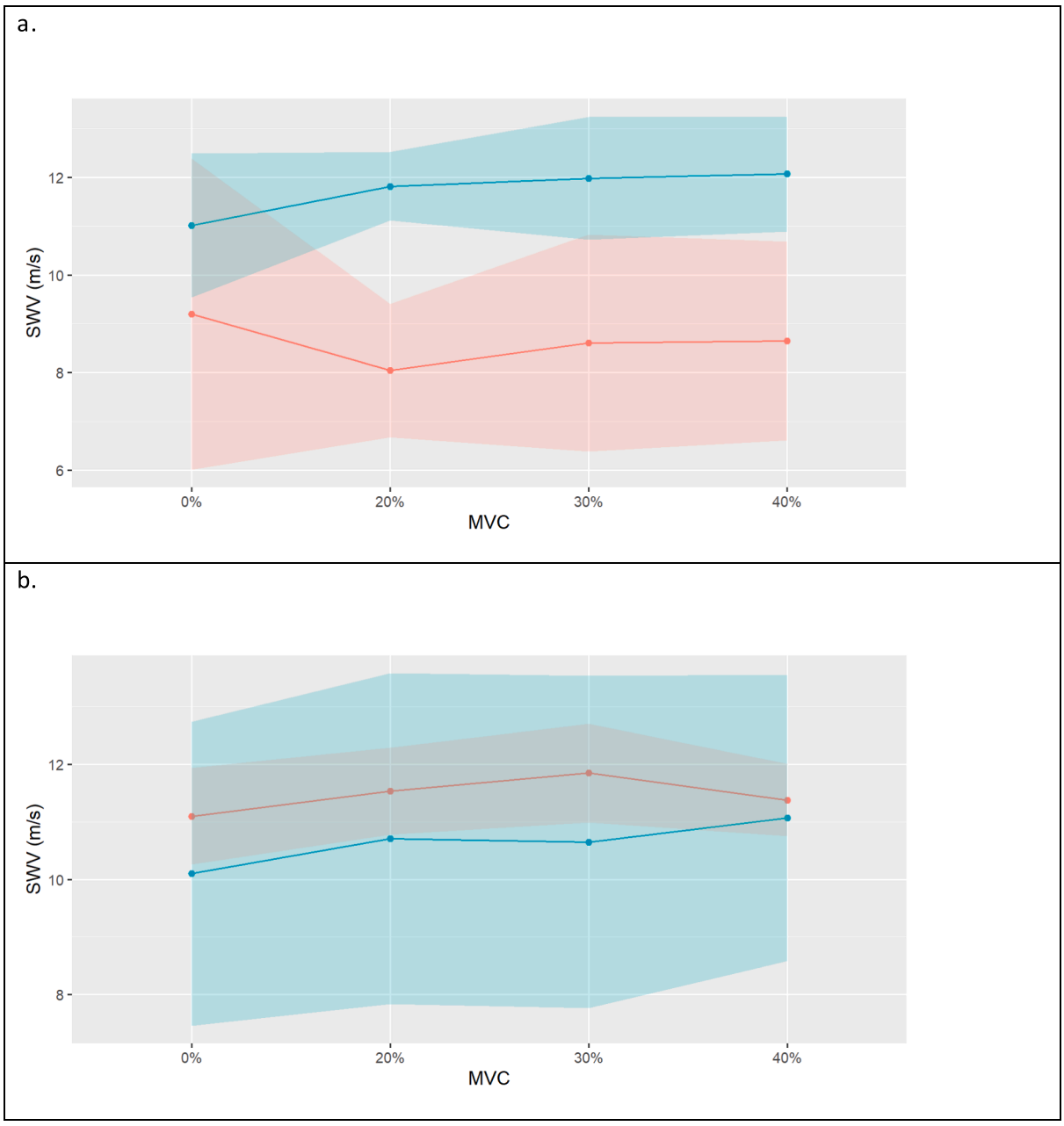

Fig. 3. Latent class analysis for SWE when pressure was on (a) and pressure was off (b). Two separate groups of participants were identified under the pressure condition (green and red lines). No obvious subgrouping was shown for the participants during the no pressure condition. Lines and shading represent the mean and 95%CI respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

established CEO tendinopathy would have increased the variability of our measurements due to hypoechogenic areas within the CEO. It remains to be determined how these hypoechogenic areas impact SWV measurements. Fourth, the pressure of 80 mmHg was chosen due to evidence from previous research suggesting that this would be an effective level of compression. It is possible that higher levels of compression could provide statistically significantly changes CEO SWV. Fifth, considering that CEO tendons are stiff and thin, it is probable that shear waves are guided (Brum et al., 2014; Helfenstein-Didier et al., 2016). The term guided refers to changes in tendon thickness that would influence the shear wave propagation and thus induced a biased estimate of stiffness. However, the brace was placed five cm distal from the lateral epicondyle, which makes it unlikely that changes in thickness occurred and would influence our main result. Finally, this was an exploratory study and the inclusion of affected participants in future studies will be useful.

5. Conclusion

A counterforce brace inflated to 80 mmHg does not reduced loading through the CEO during a low to moderate wrist and finger extension task. It appears that the beneficial effect of counterforce braces utilised in practice may be due to other factors, which may include neurophysiological effects, contextual effects, and/or increased self-efficacy. It is however possible that the counterforce brace may have a different effect in patients with CEO tendinopathy and future research should investigate SWV in this group of people. Future studies may wish to assess whether these mechanisms mediate symptoms modification with a counter force brace use in participants with CEO symptomatic tendinopathy.

CRediT authorship contribution statement

Nico Magni: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Richard Ellis:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Conceptualization. **Leanne Bisset:** Writing – review & editing, Supervision, Methodology. **Alberto Gonzalez-Vazquez:** Writing – review & editing, Software. **Antoine Nordez:** Writing – review & editing, Supervision, Software, Methodology. **Peter McNair:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbiomech.2025.112909

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