PALMARIS LONGUS MUSCLE CONTRIBUTION TO MAXIMUM TORQUE AND STEADINESS IN HIGHLY SKILLED GRIP AND NON-GRIP SPORT POPULATIONS

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ABSTRACT

Background: The anatomy, origin, function, and appearance of the Palmaris Longus Muscle (PLM) in different populations are well studied. However, little is known about its contribution to wrist flexion movements in sports. This study investigates whether the existence or absence of the PLM affects maximal torque output or torque consistency of submaximal wrist flexion moment.

Methods: One hundred ninety-seven well-trained sports students were clinically examined to ascertain the presence of the PLM. Forty of them from different sport disciplines were assigned to two groups (athletes in handgrip sports: HG, athletes in non-handgrip sports: NHG). Their 80 upper limbs were divided based on the PLM-presence/absence and hand-dominance/non-dominance. Maximal Isometric Torque (MIT) at 150º, 180º, and 210º wrist angle, and torque steadiness at 150º and 180º, at 25%, 50%, and 75% of MIT were measured on a Humac Norm dynamometer.

Results: In all MIT tests, HGs significantly surpassed NHGs, independently of the dominant or non-dominant side in presence of the PLM (p <.05). Steadiness was significantly higher in HGs than in NHGs in dominant hands having the PLM, at 25% and 75% of MIT at both angles (p <.05).

Conclusions: It is concluded that the existence of the PLM provides an advantage in sustained handgrip sports (throwers, racquet sports, basketball, handball players), contributing positively to decreased torque variability and higher maximal torque independently of muscular length. Important implications for sports performance and injury prevention have also resulted.

Key words: *isometric torque, maximal torque, torque variability, laterality*

INTRODUCTION

The *Palmaris Longus* Muscle (PLM) is one of the most variable muscles of the human body (Park et al., 2010). It can have the characteristics of a phylogenetic retrograde muscle – namely, a short belly and a long tendon (Sebastin, Lim, et al., 2005). It a) acts as a weak wrist flexor, b) has its origin at the *epicondylus medialis*, and c) its insertion point is on the *aponeurosis palmaris* (Natsis et al., 2012; Schünke et al., 2016). The most common variation is its absence uni- or bilaterally in about 22.4% of the human population (Reimann et al., 1944), although there are reports that in some cases this percentage can be significantly higher and reach 63.9%, especially in Caucasian populations (Dimitriou et al., 2015).

Regarding the estimation of the functionality of the muscle for the hand, there are few related studies (Fowlie et al., 2012; Sebastin, Puhaindran, et al., 2005). Cetin, Genc, Sevil, and Coban (2013) evaluated the influence of the absence or presence of the PLM on the grip and pinch strength, concluding that there was no significant difference in hand strength between the two groups, while Gangata, Ndou, and Louw (2010) showed the contribution of the muscle in thumb abduction. Moreover, the existence of the muscle may mean a larger reservoir of receptors inside the forearm, which may be useful in reducing errors during firmly holding an object or in increasing gripping accuracy. The muscle spindles found in the muscle belly are thought to be responsible for the sensation of position and movement of the limb (Winter et al., 2005). Finally, histological studies have shown the presence of Ruffini and Pacini mechanoreceptors and Golgi's tendon organs in the PLM (Jozsa et al., 1993).

To date, controversial findings exist about the function of the PLM in sports. There are doubts about how important the PLM is for handgrip (Eric et al., 2019; Vercruyssen et al., 2016), while other researchers support that the PLM contributes, or even provides, an advantage to handgrips used in sports such as basketball, handball, wrestling, tennis, badminton, rowing, etc (Fowlie et al., 2012). Specifically, they found that the presence of the PLM was higher amongst both elite and non-elite athletes competing in "sustained grip" sports compared with "intermittent grip" sports. During sustained gripping in sports, submaximal isometric co-contraction of carpo-metacarpal flexors and finger flexors is required to maintain a stable grip (Chow et al., 1999; Wei et al., 2006). In addition, Wadsworth (1983) reported that the PLM's contribution to the metacarpal flexion could lead to a stronger and more stable grip. The PLM, with a greater pool of proprioceptors, may provide athletes participating in sustained grip sports with a superior grip precision.

The relationship between torque variability and handgrip performance in sports has been better defined by Hamilton and Wolpert (2002) and Harris and Wolpert (1998). They suggested that the application of steady isometric force from the wrist flexors to the tennis racquet and to the ball in handball and basketball might be of great importance for the goal-directed movement. Moreover, it has been reported that highly skilled tennis and handball players showed a significantly lower coefficient of torque variability at all examined submaximal isometric wrist contractions than sedentary individuals (Salonikidis et al., 2009). Neural and mechanical mechanisms seem to underlie the torque steadiness during isometric actions (Enoka et al., 2003). However, the exact physiological mechanism behind the differences in torque steadiness between highly skilled and novice athletes is not well understood. Therefore, it could be of practical interest to study whether the presence of the PLM as an additional wrist flexor in systematically trained hand grippers might further stabilize the wrist joint and lead to better torque steadiness and performance.

To our knowledge, there has been no published research examining the function of the PLM during isometric contractions and it is difficult to determine whether its presence contributes in, or even provides an advantage to, handgrips used in sports. Based on the current literature, the presence of the PLM: i. Is higher amongst athletes participating in sports that require handgrip, ii. May assist metacarpal flexion in the contraction of muscles around the wrist, iii. Helps maintain steadiness, and iv. Improves precision due to the additional muscle spindles and mechanoreceptors (Fowlie et al., 2012).

For these reasons, further research is required to determine whether the actual function of the PLM may be advantageous in providing a more stable grip that is required in a higher level of skill between athletes performing grip sports. We hypothesise that the existence of the PLM affects the ability to provide a constant application of submaximal strength in HGs more than in NHGs during a range of wrist angles. Secondly, we hypothesise that the presence of the PLM provides an advantage to maximum strength in athletes in handgrip sports.

METHODS

Participants

The sample consists of young athletes of both sexes who have not yet started with their occupational careers. Initially, 197 volunteer sports students (18-25 yrs.) from different sport disciplines were examined to determine the existence of the PLM in their forearms. Then, 40 athletes (20 males and 20 females) were deliberately assigned to two groups; 20 participants without PLM (10.15% from the initial sample) and an identical second group of 20 participants with PLM were selected for statistical reasons of comparison. Out of these 40 participants, 26 (15 males, and 11 females) were active in sports disciplines with high (HG) wrist involvement (11 track and field throwers, 2 pole-vault athletes, and 5 basketball, 4 handball, 4 tennis, and 2 volleyball players) and 14 (5 males, and 9 females) participated in disciplines with no wrist (NHG) involvement (5 football players, 5 runners, 2 long jumpers, and 2 dancers). Their anthropometric characteristics are shown in Table 1.

Table 1. *Demographic and anthropometric characteristics of the two group members (n=40)*

	HG			NHG		
Gender	**age (yrs.)**	**height (cm)**	**weight (kg)**	**age (yrs.)**	**height (cm)**	**weight (kg)**
Male	20.1±1.8	172.9±4.0	71.65±5.3	20.8±1.2	178.4±6.0	76.85±7.9
Female	20.4±3.2	168.3±3.0	67.85±8.3	19.6±1.4	162.9±5.0	69.32±6.9

(HG = "athletes in handgrip sports", NHG = "athletes in non-handgrip sports").

Unequal group-sizes occurred during the selection process and we decided to test everyone instead of rejecting individuals from the beginning. Their 80 hands were assigned into a) dominant and b) non-dominant and into i. Hands having the PLM and ii. Hands without the PLM. All test participants were admitted to the survey provided they had no anamnesis or recent injury of the wrist, the fingers, and the forearm, either on the right or the left side. Also, six participants from the initial sample who were found to be ambidextrous were excluded from the research. Approval for the experiment was obtained from the institutional ethics committee on human research in accordance with the declaration of Helsinki and written consent was obtained from each participant.

Data acquisition

An individual assessment form was used to record the demographic data, the setting of the device, and the performance of each participant. Moreover, all participants filled out the "16-question Handedness Questionnaire", to determine their dominant hand (Tran et al., 2014). The tests were carried out on a calibrated isokinetic dynamometer (HUMAC NORM – CSMi Medical Solutions, Stoughton, MA). The sampling frequency of the device was set at 100 Hz (torque measurement accuracy is ± .5%). The participants were fastened to the device seat and their wrists were stabilised according to the instructions of the manufacturer's operating manual. The angle of 180º was selected as the neutral position of the wrist joints since this position corresponds to "anatomical zero".

Their forearms were in a supine position so that their palms faced upwards. With a goniometer (Model 01135, Lafayette), the elbow angle was positioned at 160º, aiming at minimising the involvement of the biceps muscle.

Measurement process

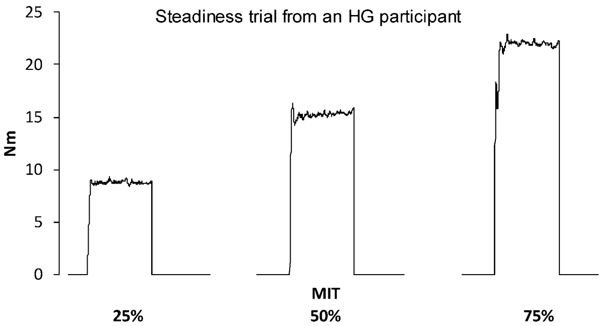
Initially, the presence/absence of the PLM in both hands was examined with the "Schaeffer's test" (opposing the thumb to the little finger and flexing the wrist) (Johnson et al., 2020). Subsequently, those who showed absence of the PLM in this test were subjected to further examination with the following four tests: "Thompson's test" (involves flexion of fingers to make a fist, followed by wrist flexion, and then opposing the flexed thumb over the fingers), "Mishra's test I" (passive hyperextension of the metacarpophalangeal joints, followed by resisted active flexion at the wrist), and "Mishra's test II" (resisted abduction of the thumb), as described by (Johnson et al., 2020), and "Pushpakumar's two-finger sign" (index and middle fingers are fully extended, the other fingers and the wrist are flexed and finally the thumb is both opposed and flexed), as Pushpakumar, Hanson, and Carroll (2004) suggest. Only when in all five tests the PLM was not detected, then the muscle was considered as completely absent. For the measurements of MIT and the steadiness during the wrist flexion, two protocols were followed and prior to the start of the tests a standardised 5-minute warm-up of the wrist muscles took place by both resistances and stretching.

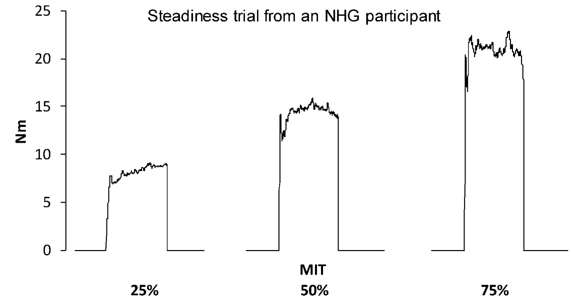
The first protocol included measurements of maximum isometric torque of the wrist joint in both hands, which was recorded at three angles: 180º (neutral position), 150º (slight bended wrist), and 210º (slight extended wrist). The side-starting-order of the attempts was random to avoid any fatigue effects. In each position, two valid trials of 5 s duration were recorded. Between each of the two trials, there was a 1-min-rest, and during each angle change, a 2-min-rest was allowed.

Participants were familiarised with the testing procedures in an extra session a week prior to the main measurements. During the main efforts, continuous verbal encouragement was given, so that the participants could achieve their best possible performance. After 3 days from the initial test, the steadiness of the isometric torque production during wrist flexion was measured, due to the second protocol, at 150º and 180º wrist angle. Meanwhile, for each participant, the individual power percentages they had achieved were calculated. Again, the starting order of each side was randomly chosen. Participants were given the opportunity to monitor their performance on a computer screen in real time, both as a number and as a graph (bar chart), so they could try to produce a constant torque. At both wrist positions and for every percentage, two valid attempts of 10 s were recorded. The targeted torque levels were set at 25%, 50%, and 75% of the individual MIT. Between the two trials at 25%, there was a 30 s rest, at 50% a 1-min-rest, and at 75% a 2-min-rest. During the change from 25% to 50% a 1-min-rest and from 50% to 75% a 2-min-rest were given. Similarly, to the initial test, there was again verbal encouragement to motivate the participants to achieve their most consistent performances.

Processing of raw data

To avoid the observed variation both in the beginning and at the end of the 10 s trial, the first two and the last two seconds were removed from all participants so that only the remaining 6 s were evaluated. Again, from the recorded two valid efforts at each percentage rate, only the most consistent one was used for statistical analysis (Figures 1a, b). The Coefficient of Variation according to the equation: $CV=(SD/Mean)\times 100$ was computed, and the resulting index was put into the SPSS program.





Figures 1a, b. *Representative best submaximal isometric constant torque (MIT) recordings at 25, 50, and 75% of MIT by "athletes in handgrip sports" (HG) and "athletes in non-handgrip sports" (NHG) who had about the same levels of strength.*

Statistical analysis

A priori analysis (Gpower 3.1) showed that at least 36 subjects in total were required to detect a moderate effect size (partial $\eta^2 p > 0.06$) among means with the statistical design performed (ANOVA with between and repeated factors) with alpha and power levels set at 0.05 and 0.80, respectively. The statistical analysis of the results was made using SPSS 25.0. For all examined variables the Means and Standard Deviations (SD) were calculated with descriptive statistics. Prior to the main data analysis, the normal distribution of the scores at the dependent variables was checked by the Kolmogorov-Smirnov test. ANOVAs with repeated measurements were applied, for both maximum strength and steadiness. The defined factors were dominance and the presence/absence of the PLM, wrist angles and levels of torque. Respectively, the dependent variables were the achieved strength performances at each tested wrist angle, in presence or absence of the PLM, both on the dominant and non-dominant side, as well as the CV-scores during the effort to apply constant submaximal moments at all percentages, which were set as the target at both angles of the wrist for both upper limb sides. As a statistical significance limit for all analyses $p < .05$ was chosen. In addition, the effect sizes were calculated using partial eta squared ($\eta^2 p$) for ANOVAs. The small, medium, and large effects would be reflected for $\eta^2 p$ in values greater than 0.0099, 0.0588, and 0.1379, respectively. The 95% confidence intervals for the differences between means (CI95%) for Tukey pairwise comparisons were calculated.

RESULTS

All statistical significance values of the Kolmogorov-Smirnoff test were found above the level of $p > .05$, thus confirming that the dependent variables followed a normal distribution. The sample was constituted from 26 HGs and 14 NHGs. In HG participants, the PLM was detected 27 times (67.5% of the hands), either uni- or bilaterally, whereas in NHGs the muscle was detected 11 times (32.5%).

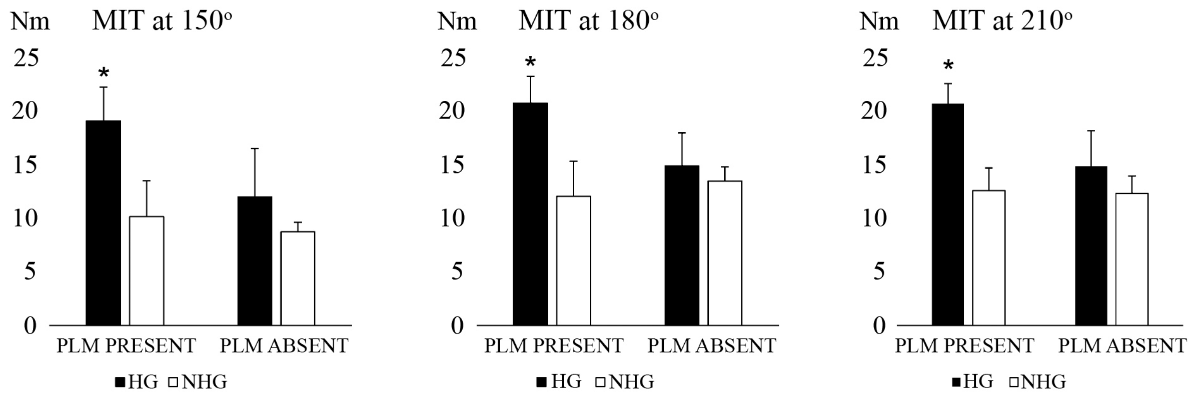
MIT

HGs surpassed the NHGs in torque performance in all three angles and in both limb sides, when having the PLM. There were differences ($p < .05$) between HGs and NHGs on the dominant side in all wrist angles and for the non-dominant limb the MIT-performances differed at 210^{O} (Table 2). Also, there were no significant torque differences ($p > .05$) between HGs and NHGs in both conditions (presence and absence of the PLM) after transposing the absolute torque values in relative ones to the body mass (N.mkg-1). There was an interaction effect between dominance and the PLM-presence (F1,36 = 2.847, p = .046, η^2p = 0.170). Pairwise comparisons showed that the presence of the PLM in the dominant limb contributed to higher torque levels independently of the different angles (CI95%: 11.260 to 15.497, 10.167 to 13.245). Interaction was also observed among group and the PLM-presence (F1,72 = 2.894, p = .044, η^2p = 0.068). Pairwise comparisons within the 2-way interaction effect revealed that HGs showed higher torque values in all three wrist angles when having the PLM, compared to NHGs (CI95%: 13.722 to 17.267, 8.554 to 13.385) for the differences between means for all statistically significant (p < .05). Pairwise comparisons did not include the zero value, suggesting that the means were different. HGs also reached higher torque at 210^{O} than NHGs in the absence of the PLM. There was not any triple interaction between three angles X groups (HG vs NHG) X PLM (presence vs absence) (Figures 2a, b, c).

Table 2. *Maximal isometric torque (Nm) for dominant and non-dominant limb of the two groups (n=40)*

	HG (n=26)			NHG (n=14)		
Limb	150^{o}	180^{o}	210^{o}	150^{o}	180^{o}	210^{o}
Dominant	14.37±6.53*	16.31±5.53*	15.81±4.80*	9.37±2.53	11.71±3.07	11.83±3.14
Non-dominant	13.14±5.35	14.87±6.20	14.20±5.20*	10.28±4.20	11.33±3.31	10.36±3.06

*(HG = "athletes in handgrip sports", NHG = "athletes in non-handgrip sports"); * p < .05, HG vs. NHG groups in dominant and non-dominant side*



*Bars depict mean values ± standard deviation (n=40); * p < .05, HG vs. NHG groups when the PLM is present.*

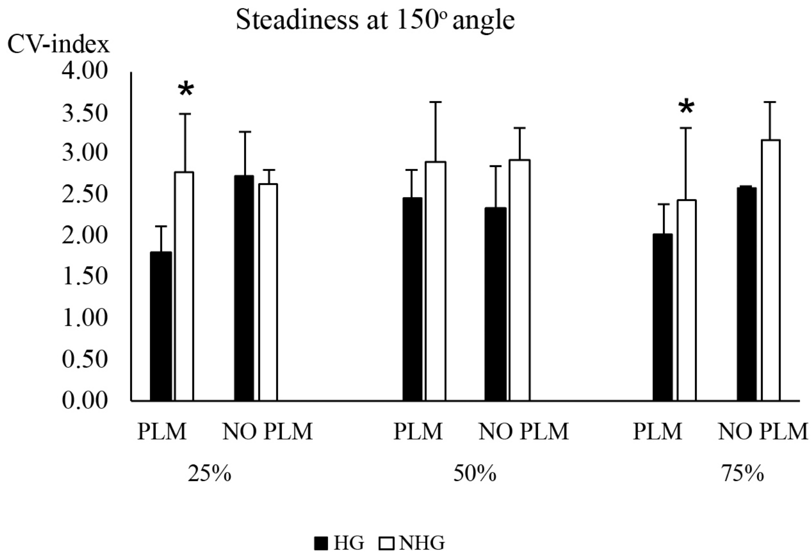
Figures 2a, b, c. *Dominant upper limb's isometric torque maximum (MIT) at three different angles (150^{o}, 180^{o}, and 210^{o}) by "athletes in handgrip sports" (HG) and "athletes in non-handgrip sports" (NHG) during isometric wrist flexion.*

Application of constant torque

There was no statistically significant effect of the factor angle on CV and no interactions were observed among angle, group, and the PLM-presence on the same variable ($p > .05$). On the contrary, there was a statistically significant main effect of the factor dominance on steadiness ($F_{1,36}$ = 14.678, p = $.001$, η^2p=

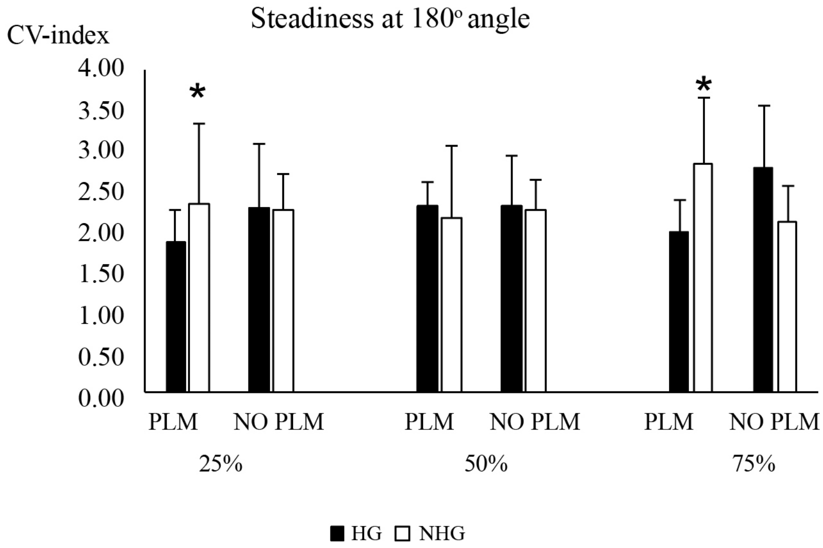
0.099). Pairwise comparisons showed that the dominant side reached higher steadiness than the non-dominant in all examined conditions (CI95%: 2.146 to 2.652, and 2.319 to 2.824). There was also interaction effect between dominance and group ($F_{1,72}$ = 3.097, *p* = *.05*, η^2p = 0.086), and between dominance and the PLM presence ($F_{1,72}$ = 3.033, η^2p = 0.068, *p* = *.039*). Pairwise comparisons within the 2-way interaction effect revealed that the HG group presented lower CV-values compared to the NHG group and the PLM-presence in the dominant side in the HG group strengthened the steadiness performance (CI95%: 2.098 to 2.520, and 2.374 to 2.950 respectively).

There was no significant main effect of the factor torque level on steadiness performance, and no interaction was observed between the factors angle and torque level (*p* > *.05*). At both angles (150º and 180º), there were differences in CV-values at the three examined levels. However, statistical marginal interaction was found among the factors angle, dominance, and torque level ($F_{2,72}$ = 2.900, *p* = *.051*, η^2p = 0.058). The dominant limb showed better steadiness at 150º in all three torque levels and at 180º in two levels (25 and 75%). A multiple interaction was found among the factors angle, dominance, group, torque level, and the PLM-presence ($F_{6,72}$ = 3.100, *p* = *.039*, η^2p=0,069). At both angles, the HG group in presence of the PLM in the dominant side showed lower CV-values at the 25% MIT-level than the NHG group. Similar results were obtained at 75% torque level for both groups. At 50%, both groups showed the same behaviour according to CV-index, independently of whether they had the PLM or not. However, the HG group presented better steadiness than the NHG group. In addition, at 180º there were no statistical differences between the two groups in steadiness performance (Figures 3 and 4).



*Bars depict mean values ± standard deviation (n=40); * p < .05, HG vs. NHG groups when the PLM is present at 25 and 75%.*

Figure 3. *Dominant limb's steadiness index (CV) in presence (PLM) and absence (NO PLM) of Palmaris Longus Muscle, at 150º wrist angle in three different submaximal torque percentages (25, 50, and 75%) by "athletes in handgrip sports" (HG), and "athletes in non-handgrip sports" (NHG).*



*Bars depict mean values ± standard deviation (n=40); * p < .05, HG vs. NHG groups when the PLM is present at 25 and 75%.*

Figure 4. *Dominant limb's steadiness index (CV) in presence (PLM) and absence (NO PLM) of Palmaris Longus Muscle, at 180° wrist angle in three different submaximal torque percentages (25, 50 and 75%) by "athletes in handgrip sports" (HG), and "athletes in non-handgrip sports" (NHG).*

DISCUSSION AND IMPLICATIONS

The main findings of this study were that grip-sports students having the PLM in their dominant hand presented a greater ability to perform steady submaximal isometric wrist flexions at 25% and 75% of MIT compared to non-grip-sports students. The greater steadiness was not muscle length specific. The HG-group outmatched the NHG-group in MIT performance in all experimental conditions, especially when the PLM was present. The above findings confirm the initial hypothesis that the existence of the PLM affects the ability to exert a constant submaximal strength in different wrist angles, but also, that the presence of the PLM provides an advantage to maximum strength in athletes involved in hand-grip-sports.

In many sports, such as basketball, handball, wrestling, tennis, badminton, rowing, volleyball, the performances during wrist flexion movements are critical to the overall performance of an athlete in skills that require the development of high levels of maximum strength, as well as high-quality steadiness in the maintenance of submaximal torque.

Salonikidis et al. (2009) suggested that experts were more accurate than sedentary young adults having the same level of force and this result was not due to differences at the level of muscles activation patterns. Therefore, the extended practice of the skill-trained individuals in a specific skill may affect the strength variability during submaximal torque testing rather than strength level. In the same line, our study showed that HGs have more frequent presence of the PLM in the often-used hand than NHGs and that this is accompanied by a higher MIT and greater ability to perform steady submaximal isometric wrist flexions at all tested levels of torque. Our findings are supported by Fowlie et al. (2012) members of sports clubs and national athletes. Methods: Participants were invited to complete a questionnaire that assessed their main sport, elite or non-elite level of participation, and level of activity. The presence of the palmaris longus was assessed visually using a standardised test. Main outcome measures: Presence of the palmaris longus, type of hand grip required for the sport and the level of participation. Results: The presence of the palmaris longus was higher in elite athletes (21/22, 96%, who demonstrated that the PLM-presence was more frequent amongst both elite and non-elite athletes competing in sustained grip sports compared to intermittent grip sports. These results suggest that the presence of the PLM may be of benefit to sustained and intermittent grip sports that require a higher level of skill and more accuracy.

In elite grip sports, increased steadiness may provide more precise execution of the actions and reduced errors. Previous studies supported the suggestion that the presence of the PLM may also assist in metacarpal flexion via its attachment to the palmar aponeurosis, and its contribution to the action of metacarpal flexion may provide a stronger and more stable grip which is important for a cylindrical grip (Sebastin, Lim, et al., 2005; Wadsworth, 1983). The palmaris longus, also with a greater pool of proprioceptors, can contribute to superior grip precision in these sports. Assuming that the PLM, when present, is active in assisting metacarpal flexion, it may also assist in the contraction of muscles around the wrist to maintain steadiness and performance. The additional muscle spindles and mechanoreceptors that the PLM provides or influences, may offer an advantage in peripheral feedback for cupping the palm (Jozsa et al., 1993). The presence of the PLM may reinforce the findings of previous research that high skill HGs dominate in grip performance and steadiness.

The significantly lower torque variation in 25% of MIT at both measured wrist angles, in HGs with presence of the PLM, confirmed the above assumptions. The specific typology and mechanics of the PLM, which consist of a muscle with short belly and a long tendon, will produce more steadiness at a given torque level and could also produce sufficient forces in the muscle fiber's short lengths because of tendon elastic properties (Troiani et al., 1999). The importance of the existence of the PLM in the dominant wrist flexors on steadiness performance is demonstrated in Figures 3 and 4. When the muscle was absent, the steadiness perturbated in both groups similarly. Furthermore, at 75% of MIT, when the requirements on torque production are increased, the presence of the PLM is more important for the joint steadiness and the steady torque application, adding more muscle activation and supporting from its mechanoreceptors, as is demonstrated in Figures 3 and 4. According to our findings, the PLM's absence at this difficult level of torque worsens the steadiness independently on the wrist angle and muscle length. To our knowledge, this is the first study that addresses the contribution of the PLM with a greater pool of muscle fibres and/or proprioceptors in the near-maximum torque and steadiness of the wrist flexors, especially in individuals participating in grip-sports.

In terms of MIT, we found better performance in HGs than in NHGs when the PLM was present, at all angles. On the other hand, it seems that the side dominance did not play any role in MIT-performance for both groups. This is in contrast with previous findings where no significant differences in MIT between high skilled and sedentary individuals were observed and this could be partially justified by the contribution of the PLM to the action of metacarpal flexion providing a stronger and more stable grip (Jubeau et al., 2006; Salonikidis et al., 2009). The existence of one more muscle may offer more strength to the joint, especially providing to athletes participating in grip sports an additional pool of muscle fibres that can be recruited for strength development.

In terms of wrist angle effect on torque development and steadiness, no significant differences were observed between both groups, suggesting that the PLM as a part of the wrist flexors is acting across the whole range of motion in a similar manner in HGs and NHGs. Especially in the extended wrist angle for the HGs, the PLM contributes further to the steadiness of the wrist joint at the increased torque level. The above finding is in line with the findings of other researchers (Friden & Lieber, 1998; Salonikidis et al., 2011).

According to steadiness and MIT-increases (%), our results did not confirm any relationship, regardless of the presence of the PLM and the skill level at both wrist angles. This is in accordance with previous studies (Löscher & Gallasch, 1993; Newell & Carlton, 1988), but it is in contrast with other studies which reported that during isometric handgrip, force tremor amplitude decreased from 5% to 60% MIT (Christou & Carlton, 2002; Laidlaw et al., 2000; Salonikidis et al., 2011). Differences in protocols, type of action, skill's expertise, muscular group, and visual feedback could only partly explain such a discrepancy. The lack of consideration of the factor existence/absence of the PLM in the previous studies could be another reason for deriving different results in the present study. The existence of the PLM seems to be important especially for the movement accuracy and grip performance in high level HGs who have more frequent presence of the PLM in the often-used hand. Moreover, HG's without PLM could be recommended a more focused training on movement accuracy and for a long time which might have a positive impact both on grip steadiness and hand flexion performance.

Injury prevention is another important consideration. Greater wrist stability in grip sports would be expected to provide added benefits when it comes to avoiding injuries – both acute and chronic ones. However, this remains to be confirmed through appropriate experimental protocols and future studies.

Several limitations need to be considered. The study had a cross-sectional design, and the participants were divided into grip and no-grip expertise regarding sports activity in which they were participating at the time of the questionnaire completion. In addition, the presence or absence of the palmaris longus in this study has not been examined against a diagnostic ultrasound or Magnetic Resonance Imaging. Moreover, the simultaneous use of EMG is thought important to estimate how and when the muscle is activated during its flexion. It is acknowledged that less-developed variations of the palmaris longus may not have been identified by the assessment procedure used in this study.

CONCLUSION

The PLM may benefit athletes who participate in sports that require a dominant-handed or two-handed grip which seems to support the first hypothesis of this study. At an applied level, this research aspires to contribute to further knowledge of whether the genetically determined presence of the PLM gives an advantage in steadiness or in the development of greater torque during wrist flexion, especially in elite grip-sports athletes. This second hypothesis has been partly confirmed. MIT was higher in the dominant hand with the presence of the PLM than the hand in which there was an absence of the PLM. The importance of the PLM-existence in individuals with extended practice in grip sports seems to be beneficial for task precision. However, further research is required to determine the actual function or benefit that the PLM may provide in cylindrical and sustained grip sports played at elite and non-elite levels.

REFERENCES

Cetin, A., Genc, M., Sevil, S., & Coban, Y. K. (2013). Prevalence of the palmaris longus muscle and its relationship with grip and pinch strength: A study in a Turkish pediatric population. *Hand*, 8(2), 215–220. https://doi.org/10.1007/s11552-013-9509-6

Chow, J. W., Carlton, L. G., Lim, Y. T., Shim, J. H., Chae, W. S., & Kuenster, A. F. (1999). Muscle activation during the tennis volley. *Medicine and Science in Sports and Exercise,* 31(6), 846–854. https://doi.org/10.1097/00005768-199906000-00013

Christou, E. A., & Carlton, L. G. (2002). Age and contraction type influence motor output variability in rapid discrete tasks. *Journal of Applied Physiology,* 93(2), 489–498. https://doi.org/10.1152/japplphysiol.00335.2001

Dimitriou, I., Katsourakis, A., Natsis, K., Kostretzis, K., & Noussios, G. (2015). Palmaris Longus Muscle's Prevalence in Different Nations and Interesting Anatomical Variations: Review of the Literature. *Journal of Clinical Medicine Research,* 7(11), 825–830. https://doi.org/10.14740/jocmr2243w

Enoka, R. M., Christou, E. A., Hunter, S. K., Kornatz, K. W., Semmler, J. G., Taylor, A. M., & Tracy, B. L. (2003). Mechanisms that contribute to differences in motor performance between young and old adults. *Journal of Electromyography and Kinesiology.* https://doi.org/10.1016/S1050-6411(02)00084-6

Eric, M., Yammine, K., Vasic, G., Dejanovic, M., & Karaba Jakovljevic, D. (2019). Prevalence of the palmaris longus and its impact on grip strength in elite gymnasts and non-athletes. *International Journal of Morphology,* 37(4), 1361–1369. https://doi.org/10.4067/S0717-95022019000401361

Fowlie, C., Fuller, C., & Pratten, M. K. (2012). Assessment of the presence/absence of the palmaris longus muscle in different sports, and elite and non-elite sport populations. *Physiotherapy,* 98(2), 138–142. https://doi.org/10.1016/j.physio.2011.02.006

Friden, J., & Lieber, R. L. (1998). Evidence for muscle attachment at relatively long lengths in tendon transfer surgery. *Journal of Hand Surgery,* 23(1), 105–110. https://doi.org/10.1016/S0363-5023(98)80097-X

Gangata, H., Ndou, R., & Louw, G. (2010). The contribution of the palmaris longus muscle to the strength of thumb abduction. *Clinical Anatomy,* 23(4), 431–436. https://doi.org/10.1002/ca.20960

Hamilton, A. F. de C., & Wolpert, D. M. (2002). Controlling the statistics of action: Obstacle avoidance. *Journal of Neurophysiology*, 87(5), 2434–2440. https://doi.org/10.1152/jn.2002.87.5.2434

Harris, C. M., & Wolpert, D. M. (1998). Signal-dependent noise determines motor planning. *Nature*, 394(6695), 780–784. https://doi.org/10.1038/29528

Johnson, C. C., Zusstone, E., Miller, T. T., Nwawka, O. K., Lee, S. K., & Wolfe, S. W. (2020). Clinical tests for assessing the presence and quality of the palmaris longus tendon: diagnostic accuracy of examination compared with ultrasound. *Journal of Hand Surgery: European Volume,* 45(3), 292–298. https://doi.org/10.1177/1753193419895160

Jozsa, L., Balint, J., Kannus, P., Järvinen, M., & Lehto, M. (1993). Mechanoreceptors in human myotendinous junction. *Muscle & Nerve,* 16(5), 453–457. https://doi.org/10.1002/mus.880160503

Jubeau, M., Zory, R., Gondin, J., Martin, A., & Maffiuletti, N. A. (2006). Late neural adaptations to electrostimulation resistance training of the plantar flexor muscles. *European Journal of Applied Physiology,* 98(2), 202–211. https://doi.org/10.1007/s00421-006-0264-z

Laidlaw, D. H., Bilodeau, M., & Enoka, R. M. (2000). Steadiness is reduced and motor unit discharge is more variable in old adults. *Muscle & Nerve*, 23(4), 600. https://doi.org/10.1002/(sici)1097-4598(200004)23:4<600::aid-mus20>3.3.co;2-4

Löscher, W. N., & Gallasch, E. (1993). Myo-electric signals from two extrinsic hand muscles and force tremor during isometric handgrip. *European Journal of Applied Physiology and Occupational Physiology,* 67(2), 99–105. https://doi.org/10.1007/BF00376651

Natsis, K., Didagelos, M., Manoli, S. M., Vlasis, K., Papathanasiou, E., Sofidis, G., & Nerantzidou, X. (2012). Fleshy palmaris longus muscle - A cadaveric finding and its clinical significance: A case report. *Hippokratia*, 16(4), 378–380.

Newell, K. M., & Carlton, L. G. (1988). Force Variability in Isometric Responses. *Journal of Experimental Psychology: Human Perception and Performance,* 14(1), 37–44. https://doi.org/10.1037/0096-1523.14.1.37

Park, M. J., Namdari, S., & Yao, J. (2010). Anatomic variations of the palmaris longus muscle. *American Journal of Orthopedics (Belle Mead, N.J.),* 39(2), 89–94. http://www.ncbi.nlm.nih.gov/pubmed/20396682

Pushpakumar, S., Hanson, R., & Carroll, S. (2004). The "two finger" sign. Clinical examination of palmaris longus (PL) tendon. *Br J Plast Surg,* 57(2), 184–185. https://doi.org/10.1016/j.bjps.2003.11.024

Reimann, A. F., Daseler, E. H., Anson, B. J., & Beaton, L. E. (1944). The palmaris longus muscle and tendon. A study of 1600 extremities. *The Anatomical Record,* 89(4), 495–505. https://doi.org/10.1002/ar.1090890408

Salonikidis, K., Amiridis, I. G., Oxyzoglou, N., Giagazoglou, P., & Akrivopoulou, G. (2011). Wrist flexors are steadier than extensors. *International Journal of Sports Medicine,* 32(10), 754–760. https://doi.org/10.1055/s-0031-1280777

Salonikidis, K., Amiridis, I., Oxyzoglou, N., De Villareal, E. S. S., Zafeiridis, A., & Kellis, E. (2009). Force variability during isometric wrist flexion in highly skilled and sedentary individuals. *European Journal of Applied Physiology,* 107(6), 715–722. https://doi.org/10.1007/s00421-009-1184-5

Schünke, M., Schulte, E., Schumacher, U., & Voll, M. (2016). Allgemeine Anatomie und Bewegungssystem. In *Allgemeine Anatomie und Bewegungssystem.* https://doi.org/10.1055/b-004-129726

Sebastin, S. J., Lim, A. Y. T., Bee, W. H., Wong, T. C. M., & Methil, B. V. (2005). Does the absence of the palmaris longus affect grip and pinch strength? *Journal of Hand Surgery,* 30(4), 406–408. https://doi.org/10.1016/j.jhsb.2005.03.011

Sebastin, S. J., Puhaindran, M. E., Lim, A. Y. T., Lim, I. J., & Bee, W. H. (2005). The prevalence of absence of the palmaris longus - A study in a Chinese population and a review of the literature. *Journal of Hand Surgery*, 30(5), 525–527. https://doi.org/10.1016/j.jhsb.2005.05.003

Tran, U. S., Stieger, S., & Voracek, M. (2014). Evidence for general right-, mixed-, and left-sidedness in self-reported handedness, footedness, eyedness, and earedness, and a primacy of footedness in a large-sample latent variable analysis. *Neuropsychologia,* 62(1), 220–232. https://doi.org/10.1016/j.neuropsychologia.2014.07.027

Troiani, D., Filippi, G. M., & Andreasi Bassi, F. (1999). Nonlinear tension summation of different combinations of motor units in the anesthetized cat peroneus longus muscle. *Journal of Neurophysiology,* 81(2), 771–780. https://doi.org/10.1152/jn.1999.81.2.771

Vercruyssen, J., Scafoglieri, A., & Cattrysse, E. (2016). The impact of palmaris longus muscle on function in sports: An explorative study in elite tennis players and recreational athletes. *Journal of Functional Morphology* *and Kinesiology,* 1(2), 167–182. https://doi.org/10.3390/jfmk1020167

Wadsworth, C. T. (1983). Clinical anatomy and mechanics of the wrist and hand. *Journal of Orthopaedic and Sports Physical Therapy,* 4(4), 206–216. https://doi.org/10.2519/jospt.1983.4.4.206

Wei, S. H., Chiang, J. Y., Shiang, T. Y., & Chang, H. Y. (2006). Comparison of shock transmission and forearm electromyography between experienced and recreational tennis players during backhand strokes. *Clinical Journal of Sport Medicine*, 16(2), 129–135. https://doi.org/10.1097/00042752-200603000-00008

Winter, J. A., Allen, T. J., & Proske, U. (2005). Muscle spindle signals combine with the sense of effort to indicate limb position. *Journal of Physiology,* 568(3), 1035–1046. https://doi.org/10.1113/jphysiol.2005.092619

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