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The influence of glove and hand position on pressure over the ulnar nerve during cycling

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ABSTRACT

Background: Chronic ulnar nerve compression is believed to be the primary cause of sensory and motor impairments of the hand in cyclists, a condition termed Cyclist's Palsy. The purpose of this study was to quantitatively evaluate the effects that hand position and glove type can have on pressure over the ulnar nerve, specifically in the hypothenar region of the hand.
Methods: Thirty-six experienced cyclists participated. Subjects rode at a constant cadence and power output on a stationary bicycle with their hands in the tops, drops and hoods of a standard drop handlebar. A high resolution pressure mat was used to record hand pressure with no gloves, unpadded gloves, foam-padded gloves and gel-padded gloves. Wrist posture was simultaneously monitored with a motion capture system. Laser scans of the subject's hand were separately acquired to register pressure maps onto the hand anatomy.
Findings: Average peak hypothenar pressures of 134–165 kPa were recorded when cyclists did not wear gloves. A drops hand position induced the greatest hypothenar pressure and most extended wrist posture. Padded gloves were able to reduce hypothenar pressure magnitudes by 10 to 28%, with slightly better pressure reduction achieved using thin foam padding.
Interpretation: The hand pressure magnitudes and loading patterns seen in steady-state cycling are of sufficient magnitude to induce ulnar nerve damage if maintained for long periods. Wearing padded gloves and changing hand position can reduce the magnitude and duration of loading patterns, which are both important to mitigate risk for Cyclist's Palsy during extended rides.

1. Introduction

Sensory and motor impairments of the hand are common among both amateur and experienced bicyclists (Black et al., 2007; Braithwaite, 1992; Capitani and Beer, 2002; Eckman et al., 1975; Haloua et al., 1987; Hankey and Gubbay, 1988; Kalainov and Hartigan, 2003; Maimaris and Zadeh, 1990; Noth et al., 1980; Patterson et al., 2003; Woischneck et al., 1993). This condition, termed Cyclist's Palsy, most often presents as numbness and/or paresthesia in the fifth and ulnar aspect of the fourth finger, sometimes accompanied with weakness in the abductors or adductors of these fingers (Kennedy, 2008; Richmond, 1994). For example, Anderson and Bovim (Andersen and Bovim, 1997) interviewed 169 cyclists after completion of a 540 km race and found sensory symptoms present in 40% of riders while 19% exhibited motor symptoms. The duration of Cyclist's Palsy varies widely among riders, persisting anywhere from several days to months (Akuthota et al., 2005; Cherington, 2000; Mellion, 1991). Further, the condition can occur as either bilateral or unilateral neuropathy, with the dominant hand being more frequently involved in unilateral cases (Cherington, 2000).

Persistent ulnar nerve compression is believed to be the primary cause of Cyclist's Palsy (Kalainov and Hartigan, 2003; Woischneck et al., 1993). The ulnar nerve passes into the hand ulnarly to the pisiform and radially to the hamate, via Guyon's Canal (Akuthota et al., 2005). Upon exiting the canal, the nerve bifurcates into superficial sensory and deep motor branches. The sensory branch provides sensation to the fifth finger and half of the fourth finger while the motor branch innervates the hypothenar muscles as well as several other small muscles groups in the hand (Kennedy, 2008). Guyon's Canal is located relatively superficially, making the ulnar nerve susceptible to compression when pressure is placed over the hypothenar region (Fig. 1) of the hand (Black et al., 2007; Richmond, 1994). Because of this, measures to prevent Cyclist's Palsy, such as wearing padded gloves and frequently changing hand position, are typically aimed at reducing the magnitude or duration of hypothenar loading (Capitani and Beer, 2002; Kennedy, 2008; Patterson et al., 2003; Richmond, 1994). The effect of these preventive measures on

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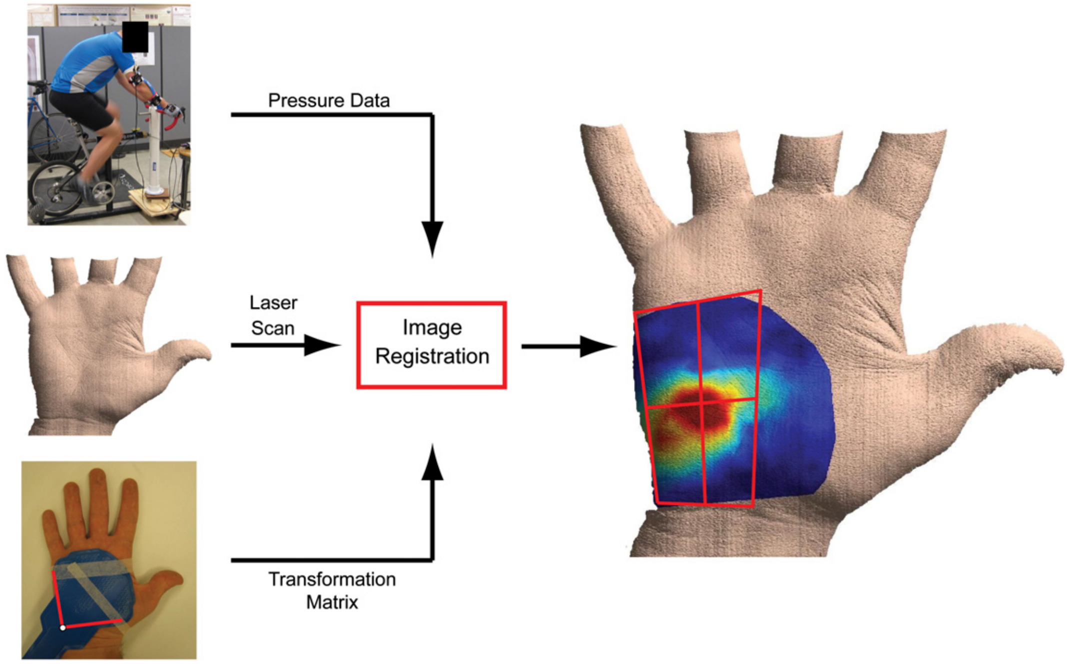

Fig. 1. Subjects rode a stationary bicycle at a constant cadence and power output while glove type and hand position were randomly varied. A piezo-capacitive pressure mat recorded pressure distributions over the hypothenar eminence of the subject's dominant hand. A three-dimensional laser scanner was used to obtain the surface coordinates of the subject's hand with and without the pressure mat attached. The origin and axes of the pressure mat were visible in these laser scans, allowing for the calculation of a transformation matrix relating the coordinates of each individual sensor within the pressure mat to the hand reference frame. Finally, the collected pressure data was co-registered with the laser scans in order to relate pressure distributions to the underlying anatomy. Peak pressures were quantified in four regions of interest (RoIs) that encompassed the hypothenar region of the hand, which is indicated by the outer bounding box within the figure.

ulnar nerve loading has not been determined. Aside from direct hypothenar loading, maintaining an extended wrist posture may also contribute to Cyclist's Palsy symptoms by inducing tension on both the ulnar nerve (Patterson et al., 2003) and the median nerve within the carpal tunnel (Mogk and Keir, 2008).

The purpose of this study was to evaluate the effects that hand position and glove type have on wrist posture and pressure over the hypothenar region of the hand. Specifically, we considered tops, drops and hoods hand positions used by road cyclists. We also compared gloves that were padded with either gel or foam materials located over the metacarpals, hypothenar eminence and thenar eminence. Our primary hypothesis was that padding would act to reduce pressure, with the greatest amount of pressure reduction found when using a compliant material. Our secondary hypothesis was that putting the hands in the drops would result in an extended wrist position and also induce the greatest load on the hypothenar region of the hand, due to the large amount of body weight that is shifted forward in this position (Potter et al., 2008). The information obtained in this study can provide a scientific basis for evaluating interventions that diminish the potential for Cyclist's Palsy to occur.

2. Methods

2.1. Participants

Thirty-six experienced cyclists, evenly divided into males (age, 40.2 years (SD 13.8); height, 180 cm (SD 8); mass, 82 kg (SD 14)) and females (age, 37.1 years (SD 12.7); height, 170 cm (SD 7); mass, 80 kg (SD 5)), were recruited from local cycling groups. All subjects were actively road bicycling for three or more hours per week for at least one year prior to participating in the study. Subjects had no history of cardiovascular, pulmonary, neurological or musculoskeletal impairments, and had no prior orthopaedic surgery performed on either upper extremity. Participants gave written informed consent in accordance with a protocol approved by the University of Wisconsin's Social and Behavioral Sciences Institutional Review Board.

2.2. Procedures and instrumentation

An adjustable stationary bicycle was configured to match the dimensions (seat tube angle, saddle height, handlebar height, reach and width) of each subject's personal road bicycle. The bicycle was outfitted with a gender-specific saddle (Bontrager inForm RL, Trek Bicycle Corporation, Waterloo, WI, USA) that was leveled to ground. For a subset of subjects ($N = 18$), the saddle was mounted on a three-dimensional load cell (JR3, Woodland, CA, USA) which recorded the net saddle forces throughout testing. Gender-specific drop handlebars, the same width as those on the subject's personal cycle, were mounted on the bicycle (males: Race 31.8, females: VR 31.8, Bontrager, Trek Bicycle Corporation, Waterloo, WI, USA). An instrumented rear hub (PowerTap Pro, Saris Corp, Madison, WI, USA) on the bicycle provided subjects with real-time feedback of power output and pedaling cadence. Subjects warmed up for 5 to 10 min at a self-selected cadence and trainer resistance that they deemed equivalent to a typical 1 to 2 hour tempo ride. The resistance level, cadence and corresponding power output was recorded and maintained for all subsequent cycling trials in which data was collected. Cadence and average power output were 80 rpm (SD 12) and 159 W (SD 47) for male subjects, and 84 rpm (SD 10) and 116 W (SD 43) for females.

Hand pressure distributions were monitored at 50 Hz using a piezo-capacitive pressure mat (Elastisens-FO44; Novel GmbH, Munich, Germany). The mat consisted of 229 sensors (4.4 mm per side) arranged in a rectangular grid. Laser scans of the hand with and without the pressure mat attached were taken to relate pressure profiles to the underlying anatomy (Fig. 1). We first performed a three-dimensional laser scan (y-axis resolution of 0.5 mm) of the ventral aspect of their dominant hand (ShapeGrabber A1300; ShapeGrabberTM Inc, Ottawa, Ontario). An impression of the dorsal aspect of the hand was made in modeling compound (Play-Doh, Hasboro

Inc., Pawtucket RI, USA) to ensure consistent positioning during the scan. The pressure mat was then secured over the hypothenar eminence of the dominant hand via adhesive tape, such that the mat origin was located above the pisiform bone and the edge of the mat was aligned with the medial aspect of the palm (Fig. 1). Subjects then re-positioned their hand in the impression and a second laser scan of the hand was obtained with the mat in place.

Each subject performed a series of cycling trials in which glove type (Table 1) and hand position (Fig. 3) were randomly varied. Subjects rode with no gloves, unpadded gloves, two foam-padded gloves (3 and 5 mm thickness) and two gel-padded gloves (3 and 5 mm thickness). Padding in the gloves was positioned over the thenar eminence, hypothenar eminence and metacarpal heads. Glove size was determined based on hand circumference measurement charts (S: 15–16.5 cm, M: 16.5–18 mm, L: 18–19.5 cm, XL: 19.5–21 cm). For each glove, subjects rode with their hands in the tops, drops and hoods position (Fig. 3). Average peak pressure distributions were obtained by averaging each sensor's peak pressure measurement over twelve consecutive pedal strokes. Co-registration of the pressure mat position on the hand was achieved by digitizing the sensor origin and axes on the laser-scanned hand-mat image. These digitized points were used to calculate the transformation needed to align the mat with the hand reference frame. The sensor coordinates were then projected onto the hand surface, allowing us to display the sensor pressure data onto laser-scanned hand images (Fig. 1).

Pressure data was summarized over a standardized anatomical region-of-interest (RoI) that overlies the ulnar nerve and the communicating branch between the ulnar and median nerves (Peter et al., 2000). The RoI was defined on a subject's laser-scanned hand image as the area enclosed by (1) pisiform/distal wrist crease, (2) center of distal wrist crease, (3) distal palmar crease under radial aspect of the fourth finger and (4) distal palmar crease under the ulnar aspect of the fifth finger. The RoI was further subdivided into four, equal sub-RoIs (Fig. 1). For each trial, the peak average pressure within the RoI and sub-RoIs was determined. All pressure data and image analysis was conducted in MATLAB (Mathworks, Natick, MA, USA).

2.3. Kinematics

Wrist posture was monitored using an active motion-capture system (Visualeyez VZ-4000, PhoeniX Technologies Inc, Burnaby, British Columbia). Rigid marker plates, consisting of three markers attached to a sheet of thermoplastic, were strapped to the subject's hand and forearm. Marker positions were first acquired while the subject held their arm in a relaxed position at their side, with the lower arm and hand reference frames aligned with the lab reference frame. Marker positions were then monitored at 100 Hz during the cycling trials. Three-dimensional segment orientation at each frame of the motion was determined using a singular value decomposition approach (Soderkvist and Wedin, 1993). Joint angles between the lower arm and hand were quantified via body fixed rotations, that involved wrist flexion–extension followed by ulnar–radial deviation (movement of ulnar aspect of hand towards medial side of forearm).

Table 1
Average (SD) peak pressure (kPa) over the entire hypothenar region (n = 36) for padded gloves. HE — hypothenar eminence, TE — thenar eminence, MC — metacarpal heads.

Padding[a]	Thickness (mm) [b]	Hand position[c]		
	HE–TE–MC	Tops	Drops	Hoods
Gel	3–3–3	123 (34)	147 (28)	114 (35)
Gel	5–5–3	113 (30)	142 (39)	103 (34)
Foam	3–3–3	108 (33)	133 (33)	104 (28)
Foam	5–5–3	113 (28)	128 (27)	96(32)

[a] Foam padding significantly reduced pressure relative to gel padding.
[b] For gel padding, a 5 mm thickness resulted in significantly lower pressures relative to 3 mm. This effect was not observed with foam padding, where thickness was non-significant ($P = 0.095$).
[c] The drops hand position resulted in pressures significantly higher than tops and hoods, which were found to be equivalent.

2.4. Statistical analysis

A three-way analysis of variance (ANOVA) was used to study the effects of gender, hand position (tops, drops and hoods) and glove condition (no glove, unpadded glove, and padded glove) on peak pressure within the RoI and sub-RoI's, and on the average wrist joint angles. We then performed a separate three-way ANOVA to assess the influence of padding material (gel and foam), thickness (3 mm and 5 mm) and hand position on peak hypothenar pressure. For each ANOVA, Tukey's Honestly Significant Difference (HSD) *post hoc* test was used to conduct pair-wise comparisons of main effects. The probability associated with Type I error was set at $P = 0.05$ for all observations. All statistical analysis was performed using Statistica version 6.1 (StatSoft Inc, Tulsa, OK, USA).

2.5. Materials testing

The elastic modulus of the gel and foam padding inserts (removed from the glove) were determined using displacement controlled compression tests performed on a materials testing machine (MTS Insight, MTS Systems Corporation, Eden Prairie, MN, USA) with a 50 N load cell. Standardized techniques were used for testing thin (5 mm) samples of nearly incompressible (gel) and compressible materials (foam). Gel samples were bonded to a steel mounting plate and then indented at rates of 0.5 and 5 mm min^{-1} to a maximum displacement of 400 μm using a flat 10 mm diameter steel cylindrical indenter. Applied force and displacement data were simultaneously recorded and used to estimate the Poisson's ratio and Elastic Modulus of the gel using the approach described by Zheng et al. (2009).

Foam padding inserts were machined into 15 mm diameter cylindrical specimens, giving an effective aspect ratio of 3:1. Specimens were loaded between lubricated steel compression platens and compressed at rates of 1 and 3 mm min^{-1} to a maximum displacement of 800 μm. The size of the loading platens was larger than the specimen diameter and their contact surfaces were polished to a mirror finish to reduce the effects of friction. Elastic modulus was defined as the slope of the initial linear region of the stress–strain plot obtained from these tests. Eight gel and ten foam samples were tested and the modulus values were averaged across samples for each material.

3. Results

3.1. Hand position effects

Peak hypothenar pressures were significantly greater ($P < 0.05$) with the hands in the drops position (112–140 kPa), relative to those found in the tops (36–135 kPa) and hoods (68–122 kPa) positions (Figs. 2). Conversely, the percentage of body weight supported by the saddle was significantly lower in the drops hand position (47% (SD 5)), than in the tops (51% (SD 5)) or hoods (51% (SD 5)).

Pressure distributions also varied significantly between hand positions (Fig. 3). Hand pressure in the tops position was concentrated across the distal portion of the hypothenar region. Pressure in the hoods hand position induced a more diagonal pressure pattern extending from the proximal ulnar portion of the hypothenar region. The drops hand position resulted in more even pressure measures across all 4 sub-regions of the hypothenar area of the hand (Fig. 2). Pressure magnitudes did not significantly vary between male and female cyclists for any of the hand positions.

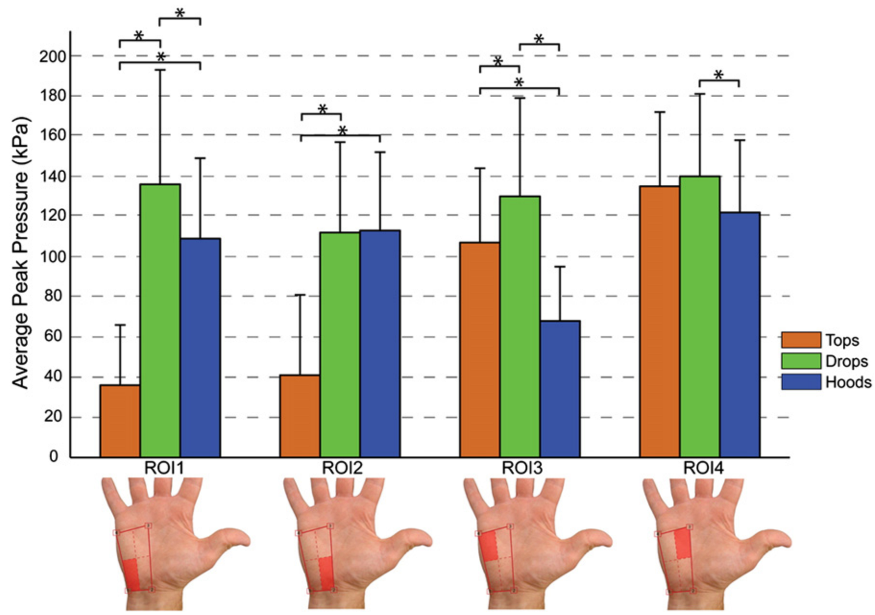

Fig. 2. Significant variations in hypothenar pressure distributions were observed with hand position (*$P<0.05$). The drops hand position resulted in the highest pressures in RoIs 1, 3 and 4. Pressure in the tops was more focused in the distal RoIs, while pressure in the hoods was concentrated in RoIs 1, 2 and 4. Data presented here is from the no glove condition.

3.2. Glove effects

Hypothenar pressure magnitudes were not significantly different between the no-glove and un-padded glove conditions. However, significantly lower hypothenar pressures were observed in the padded glove conditions, which reduced pressure relative to the no-glove condition by 19%, 21% and 29% for the tops, drops and hoods positions, respectively (Fig. 4). The use of foam padding resulted in significantly ($P<0.05$) lower peak pressure than gel padding. Increasing padding thickness from 3 to 5 mm resulted in significant pressure reduction for the gel, but had no effect when using the foam (Table 1).

3.3. Padding material properties

Compression testing revealed that the foam padding inserts were approximately 60% more compliant than the gel inserts. Specifically,

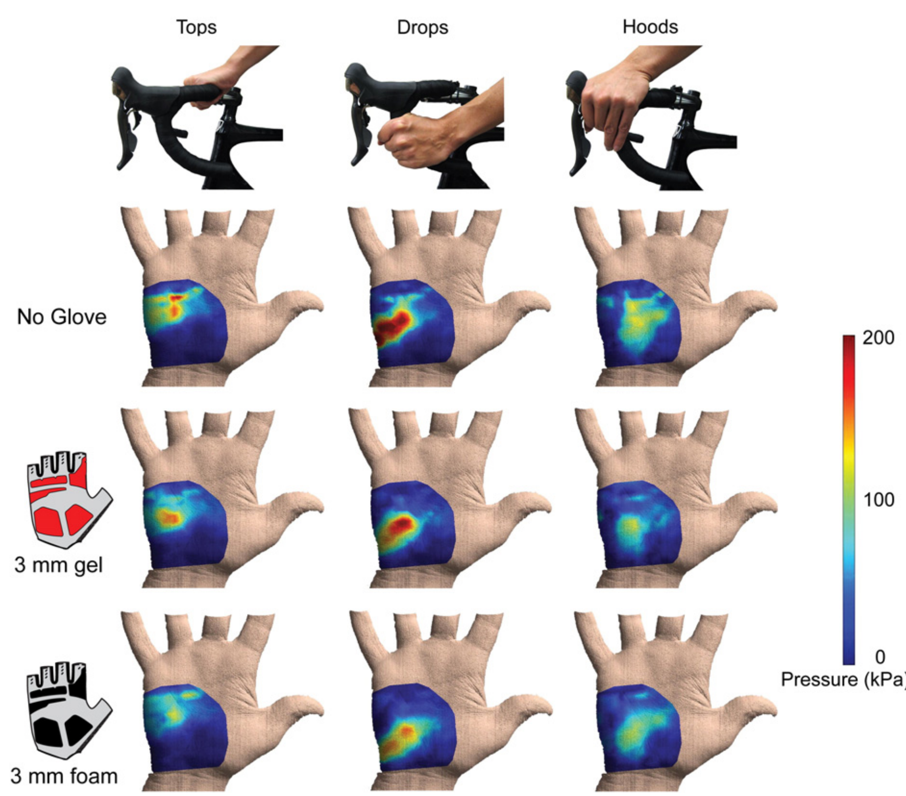

Fig. 3. Three hand positions commonly used by road bicyclists were tested in this study; tops, drops and hoods. The drops position resulted in the highest average peak pressure magnitude over the hypothenar eminence. Wearing padded gloves did not substantially vary the pressure profiles, but did diminish peak pressures as seen graphically in these images.

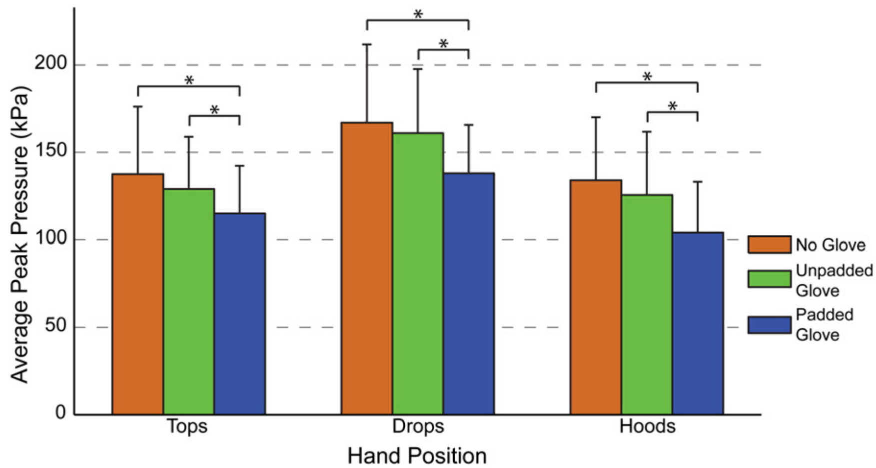

Fig. 4. Statistical analysis revealed that the no-glove and un-padded glove conditions were equivalent. Conversely, padded glove conditions significantly reduced hypothenar pressure for all hand positions, relative to the no glove and unpadded glove conditions (*$P<0.05$).

foam and gel inserts were found to have elastic moduli of 121.9 kPa (SD 8.2) and 308.7 kPa (SD 32.0), respectively. Elastic modulus did not significantly vary (foam: $P=0.55$, gel: $P=0.34$) between the two strain rates used.

3.4. Wrist posture

Wrist extension was significantly higher with the hands in the drops hand position (54°), compared to the hoods (36°) and tops hand positions (23°). Ulnar wrist deviation was significantly higher (37°) with the hands in the tops position, compared to the drops (22°) and hoods (4°) hand positions (Fig. 5). Wrist angles did not vary significantly with gender or glove type.

4. Discussion

One of the most common recommendations for preventing Cyclist's Palsy is the use of padded gloves. However to our knowledge, this is the first study that has actually assessed the effect of gloves on hand pressure distributions in cyclists. We measured peak pressures of 134–165 kPa over the hypothenar region of the hand when cyclists did not wear gloves, with the highest pressures occurring in a drops hand position. The higher hypothenar pressure in the drops likely reflects a more flexed riding posture, which required subjects to support more of their upper body weight with their hands and less with the saddle. As hypothesized, padded gloves significantly reduced peak hypothenar pressure. Reductions of 10 to 29% were achieved, with the greatest pressure reductions occurring when wearing a glove that had 3 mm foam padding. Interestingly, increasing the foam padding from 3 to 5 mm provided no significant additional pressure reduction. This result is not consistent with the common recommendation for cyclists to wear thick padded gloves (Maimaris and Zadeh, 1990; Richmond, 1994). Gel padding was found to be slightly less effective than foam padding in reducing pressures. The difference in performance between the two padding materials seems to be attributable to the greater compliance of the foam that was used.

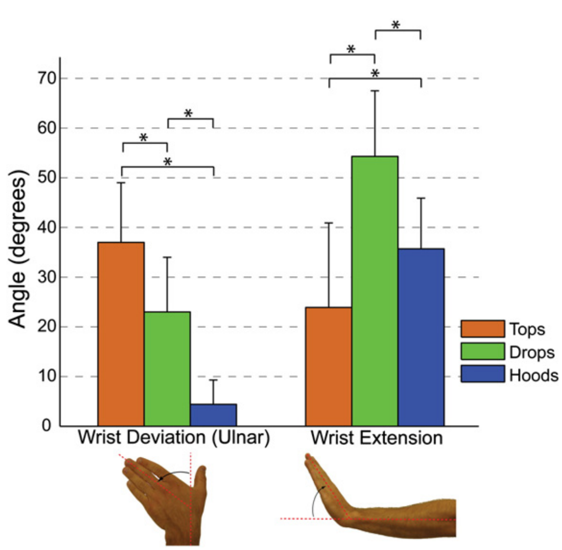

Fig. 5. Wrist postures varied significantly with hand position (*$P<0.05$). In particular, ulnar deviation was greatest with the hands in the tops hand position, while the largest wrist extension was observed with the hands in the drops hand positions.

Cyclist's Palsy can present clinically in four different manners dependent upon the location of ulnar nerve compression (Capitani and Beer, 2002). Type I occurs when compression takes place proximal to Guyon's Canal (before the nerve bifurcates) and results in sensory loss and weakness of all ulnar innervated hand muscles (Fig. 6). Type II involves compression of the deep motor branch of the ulnar nerve distal to Guyon's Canal and results in weakness of all ulnar hand muscles. Type III also involves compression of the deep motor branch distal to Guyon's Canal causing motor weakness of all ulnar innervated hand muscles expect the hypothenar group. Finally, Type IV occurs when the superficial sensory branch is compressed distal to Guyon's Canal resulting in sensory loss only (Capitani and Beer, 2002). Although the ulnar nerve only provides sensation to the fifth finger and the ulnar aspect of the fourth finger, cyclists often report experiencing paresthesia in all fingers (Akuthota et al., 2005). This observation could result from a communicating branch that often exists near the mid-section of the palm underneath the fourth finger that connects the ulnar and median nerves (Bas and Kleinert, 1999; Peter et al., 2000). As a result, sensory disturbances to the ulnar nerve could be potentially transferred to the median nerve resulting in Cyclist's Palsy symptoms developing in the remaining fingers of the hand.

Pressure distribution patterns varied significantly with hand position, which could relate to the different types of Cyclist's Palsy observed clinically. A tops hand position tended to induce pressure concentrations nearer to the superficial sensory branch (Fig. 3), which would more likely result in Cyclist's Palsy type III and IV. In contrast, the drops hand position resulted in a relatively large pressure concentration that extended distally from Guyon's Canal along the ulnar nerve. Thus, there would seem to be the potential for a drops hand position to induce any of the four Cyclist's Palsy types. Moving from the drops to the hoods

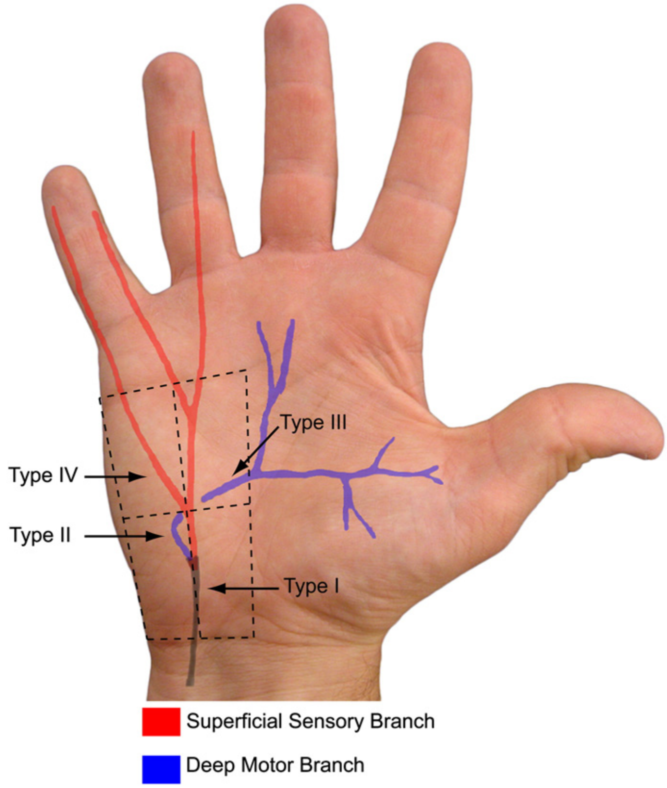

Fig. 6. Cyclist's Palsy symptoms can present differently depending on where nerve compression occurs. Type III (motor weakness except hypothenar muscles) and IV (sensory loss) would be more consistent with distal pressure concentrations as seen in the tops hand position. Types I (sensory loss and weakness of ulnar innervated hand muscles) and II (motor weakness of ulnar innervated hand muscles) would likely require more proximal pressure as seen in the drops and hoods hand positions.

reduces pressure on the ulnar side of the hypothenar region (Fig. 3), which could diminish risk for Cyclist Palsy types I, II and IV.

Surface pressure is recognized as one of the neurosensory inputs that can contribute to hand discomfort and/or pain, which can in turn lead to decreased fine motor control and function (Johansson et al., 1999). The mean pain-pressure threshold for the palm and thenar region of the hand are reported to be 494 kPa and 447 kPa, respectively (Johansson et al., 1999). However, substantially lower externally applied pressures are sufficient to induce nerve damage. Rudge et al. reported a severe/complete conduction block of the anterior tibial nerve (after 90 min) with an applied pressure of 157 kPa, a moderate/partial conduction block with an applied pressure of 98 kPa and no effect with pressures below 74 kPa. Additionally, they found that increasing the duration of compression to 180 min resulted in wallerian degeneration that required several weeks to months to heal (Rudge et al., 1974). Hypothenar pressures recorded in this study (Table 1) are well below the pain-pressure threshold, yet are sufficient to induce nerve damage if maintained for long periods. This suggests that road bicyclists could unknowingly induce localized nerve damage in the hand. While padded gloves were effective in reducing peak pressures, the magnitudes would still seem to be sufficient to contribute to nerve damage. Hence, the use of additional counter-measures, such as changing hand positions (Capitani and Beer, 2002; Kennedy, 2008; Patterson et al., 2003; Richmond, 1994), would seem prudent to mitigate risk of Cyclist's Palsy in longer duration rides.

In addition to external pressure, wrist position is believed to affect the internal loading on both the ulnar and median nerves (Capitani and Beer, 2002; Mogk and Keir, 2008; Patterson et al., 2003). In particular, an extended wrist posture can directly contribute to nerve tension (Capitani and Beer, 2002). We observed the greatest amount of wrist extension in the drops hand position (Fig. 5), which could exacerbate the potential for nerve damage to occur when riding in the drops. The tops hand position, which required the riders to places their hands on the medial portion of the handlebars, resulted in ulnar deviation of the wrist. Ulnar wrist postures can result in pressure on the median nerve within the carpal tunnel, and potentially contribute to median neuropathy (Keir et al., 2007).

The compliant, piezo-capacitive pressure mat used in this study allowed us to obtain higher resolution information than has been recorded in previous studies of bicycle interface pressures (Bressel and Cronin, 2005; Lowe et al., 2004; Potter et al., 2008). We chose to attach the pressure mat to the subject's dominant hand, which is the commonly affected hand in individuals who present with unilateral Cyclist's Palsy (Cherington, 2000). All subjects were fitted with new gloves, such that our results do not reflect changes in padding material properties that can occur with extended wear. We were only able to measure pressure arising from normal forces on the hand, though shear forces may also play a role in the development of localized tissue damage (Johansson et al., 2002). Also, we tested subjects on their own bicycle geometry and at a self-selected cadence and power output, rather than using a standardized fitting procedure and fixed cadence and power (Bressel and Cronin, 2005; Potter et al., 2008; Sauer et al., 2007). This was done so as to not introduce subjects to a novel bicycle geometry, and to reduce the potential for fatigue to set in during the testing. Finally, testing was conducted under steady-state conditions in a laboratory environment. Future studies should consider dynamic variations in hand pressure and wrist posture due to terrain, particularly among mountain bikers who more often present with medial nerve symptoms (Patterson et al., 2003).

5. Conclusion

We conclude that the hand pressure magnitudes and loading patterns seen in steady-state cycling are sufficient to induce ulnar nerve damage if maintained for long periods. Wearing a glove with thin compliant padding over the hypothenar region can reduce peak pressure by 10–29%. However, these pressures remain sufficiently high that additional counter-measures, e.g. changing hand position, seem necessary to mitigate the risk for incurring Cyclist's Palsy during longer duration rides.

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