CHAPTER 4

RESULTS

This section presents the reliability of muscle function and sensory perception related to measurement of the wrist extensors. Determination of the reliability of the measurement in this thesis consists of intraclass correlation coefficients (ICC), coefficient of variation (CV) and standard error of measurements (SEMs). All outcome measures in this thesis including muscle function and sensory perception were studied.

4.1 Reliability of muscle function and sensory perception measurements of the wrist extensors

Table 1. Intraclass correlation coefficients (ICC), coefficient of variation (CV) and standard error of measurements (SEMs) for grip strength (GS), wrist extension strength (WES), range of motion for active wrist flexion (ROM-AF) and extension (ROM-AE), and for passive wrist flexion (ROM-PF) and extension (ROM-PE), choice response time (CRT), vibration sense at lateral epicondyle (VIB-O) and the belly of the carpi radialis brevis muscle (VIB-M), joint position error for wrist flexion (JPE-F) and extension (JPE-E), cold pain at lateral epicondyle (CPT-O) and the belly of the carpi radialis brevis muscle (CPT-M) and m (CPT-M), heat pain at lateral epicondyle (HPT-O) and the belly of the carpi radialis brevis muscle (CPT-M), and pressure pain threshold at lateral epicondyle (PPT-O) and the belly of the carpi radialis brevis muscle (PPT-M).

Measurement	ICC	CV (%)	SEMs
GS	0.86	6.66	7.39 (<5%)
WES	0.95	10.51	1.70 (<5%)
ROM-AF	0.95	1.97	0.35 (<5%)
ROM-AE	0.95	2.08	0.34 (<5%)
ROM-PF	0.95	1.53	0.35 (<5%)
ROM-PE	0.97	1.00	0.18 (<5%)
CRT	0.92	5.26	0.01 (<5%)
VIB-O	0.94	17.74	0.26 (<5%)
VIB-M	0.93	13.95	0.39 (<5%)
JPE-F	-0.11	79.38	3.01 (>5%)
JPE-E	0.58	61.96	1.12 (>5%)
CPT-O	0.94	27.20	0.54 (<5%)
CPT-M	0.98	12.22	1.14 (<5%)
HPT-O	0.88	2.71	0.40 (<5%)
HPT-M	0.97	1.78	0.14 (<5%)
PPT-O	0.92	7.79	7.03 (<5%)
PPT-M	0.96	5.10	2.64 (<5%)

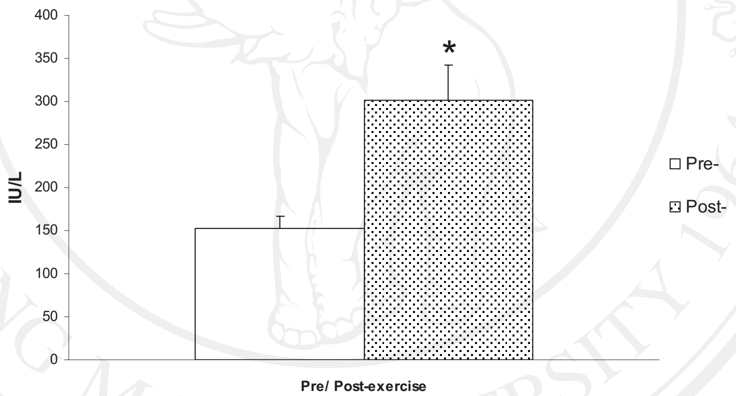
Table 1 shows the Intraclass correlation coefficients (ICC), coefficient of variation (CV) and standard error of measurement (SEMs) for all measures. All muscle function measures including grip and wrist extension strength, ROM (ROM-AF, ROM-AE) and CRT were considered to be reliable. Sensory perceptions (ROM-PF, ROM-PE, VIB, CPT, HPT, and PPT) were also reliable (ICC > 0.85), however

VIB and CPT over the origin site were greater in CV when compared to that of the other measurements. ICC, CV and SEMs all indicated that the reliability of JPE was low.

4.2 Characteristics of DOMS in the wrist extensors

4.2.1 Plasma creatine kinase (CK)

The plasma creatine kinase activity was voluntarily tested in 10 subjects at pre-exercise and the 4th day post-exercise.



* Significant difference from baseline p< 0.05.

Figure 17 Mean and standard error of mean ($\overline{X}$ ± SEM) of the plasma creatine kinase activity between pre- and the 4th day post-exercise.

The plasma creatine kinase activity at pre- and post-exercise was 152.80 ± 13.71 and 301.8 ± 40.46 IU/L., respectively. There was significantly different in plasma creatine kinase activity between pre- and post-exercise ($F_{1, 9}$ = 7.28, p = 0.024) (Figure 17).

4.2.2 Sensory perception

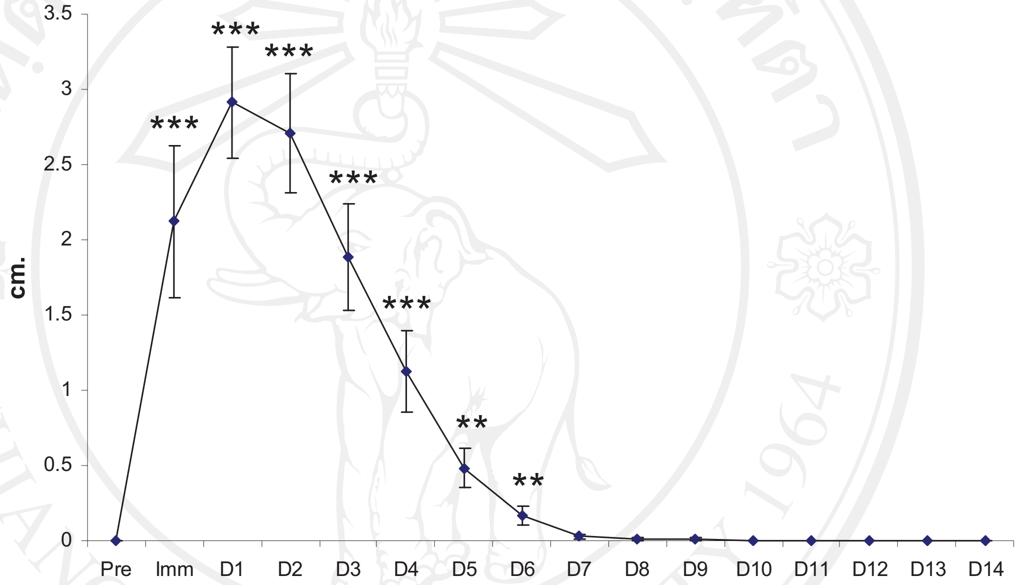
The result of sensory perception including pain intensity, pain threshold, and passive range of motion demonstrated in table 2.

Table 2. Mean ± SEM of the sensory perception measurements.

Para-meters	Pre	Imm	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14
VAS	0	2.12±0.50 P=0.000	2.91±0.37 P=0.000	2.71±0.39 P=0.000	1.89±0.35 P=0.000	1.13±0.27 P=0.000	0.48±0.13 P=0.001	0.17±0.06 P=0.009	0.03±0.02 NS	0.01±0.01 NS	0.01±0.01 NS	0 NS	0 NS	0 NS	0 NS	0 NS
LS	0	1.88±0.41 P=0.000	3.48±0.27 P=0.000	3.36±0.32 P=0.000	2.64±0.26 P=0.000	1.84±0.35 P=0.000	1.32±0.33 P=0.001	0.76±0.22 P=0.002	0.12±0.07 NS	0.04±0.04 NS	0.01±0.01 NS	0 NS	0 NS	0 NS	0 NS	0 NS
CPTO	6.79±1.84	12.31±2.24 P=0.001	10.11±2.10 P=0.032	10.19±2.11 P=0.025	9.61±1.89 P=0.026	8.00±2.06 NS	8.16±2.02 NS	7.25±1.80 NS	7.23±1.90 NS	6.92±2.02 NS	7.35±1.99 NS	6.24±1.84 NS	6.64±1.90 NS	5.95±1.74 NS	6.22±1.88 NS	6.23±1.90 NS
CPTM	9.09±2.10	12.04±2.23 P=0.013	12.22±2.24 P=0.006	12.73±2.25 P=0.004	11.51±2.09 P=0.007	11.36±2.14 P=0.013	10.81±2.10 P=0.018	10.09±2.09 NS	9.64±2.04 NS	9.93±2.26 NS	9.58±2.23 NS	9.05±2.14 NS	8.77±2.11 NS	8.68±2.12 NS	9.05±2.12 NS	8.75±2.12 NS
HPTO	45.10±0.72	43.97±0.87 NS	44.16±0.76 NS	44.50±0.81 NS	45.30±0.69 NS	45.26±0.73 NS	45.81±0.68 NS	45.99±0.72 NS	46.16±0.68 NS	46.18±0.68 NS	46.17±0.68 NS	45.81±0.74 NS	45.94±0.72 NS	46.22±0.66 NS	46.09±0.7 3 NS	45.84±0.83 NS
HPTM	44.12±0.86	43.14±0.93 NS	43.35±0.92 NS	44.02±0.80 NS	44.57±0.80 NS	44.48±0.72 NS	44.50±0.76 NS	45.39±0.78 NS	45.37±0.74 NS	45.32±0.72 NS	45.29±0.77 NS	45.16±0.80 NS	45.48±0.77 NS	45.65±0.72 NS	45.34± 0.79 NS	45.75±0.79 NS
PPTO	325.89± 15.19	294.95±15.49 P=0.005	252.43± 16.44 P<0.001	247.40± 16.23 P<0.001	267.28± 14.05 P<0.001	269.73±13.4 8 P<0.001	273.63±13.08 P=0.001	291.27±14.02 P=0.013	294.88± 11.65 P=0.027	297.17±12.43 P=0.043	301.56±11.48 P=0.047	295.17±13.00 P=0.044	302.11±11.74 NS	302.95± 13.01 NS	309.92± 12.03 NS	309.65±11.62 NS
PPTM	274.96± 12.31	237.03±14.31 P<0.001	191.01± 14.78 P<0.001	186.61± 13.41 P<0.001	202.60± 12.40 P<0.001	219.37±11.4 9 P<0.001	227.89±11.33 P<0.001	240.95±12.08 P=0.004	251.41±9.16 P=0.018	244.97±9.91 P=0.007	251.36±11.11 P=0.033	255.43±11.29 P=0.043	255.68±10.47 NS	249.68±10. 79 P=0.009	263.25± 10.69 NS	273.75±11.01 NS
ROM-PF	98.99±1.59	90.25±2.27 P<0.001	71.23±2.23 P<0.001	71.47±2.75 P<0.001	74.15±3.35 P<0.001	79.17±3.40 P<0.001	85.29±2.60 P<0.001	86.91±2.46 P<0.001	91.15±2.18 P<0.001	91.95±1.88 P<0.001	92.15±1.86 P<0.001	93.17±2.06 P=0.001	95.04±1.72 P=0.007	94.79±1.66 P=0.005	95.21± 1.62 P=0.012	96.15±1.64 P=0.016
ROM-PE	97.56±1.46	90.25±1.71 P<0.001	82.61±2.33 P<0.001	82.43±2.84 P<0.001	85.97±2.24 P<0.001	89.93±2.26 P=0.001	92.68±2.06 P=0.003	93.95±1.71 P=0.016	94.88±1.69 P=0.041	95.00±1.83 NS	95.04±1.77 NS	94.61±1.87 NS	95.96±2.01 NS	95.43±2.00 NS	96.96± 1.79 NS	97.65±1.66 NS

4.2.2.1 Pain intensity

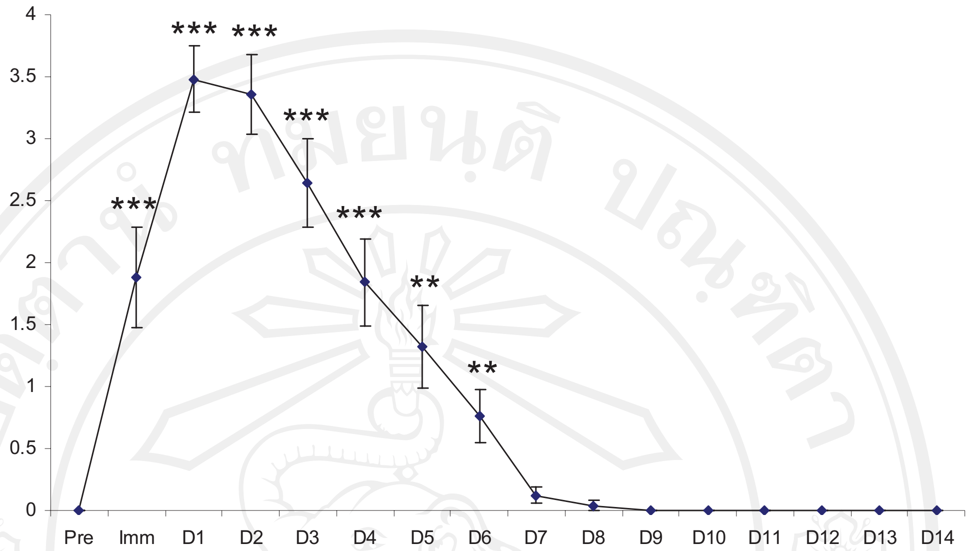
The mean scores of average pain visual analogue scale and muscle soreness level of Likert scale were evaluated from pre-exercise (baseline) until to 14 days post-exercise (Table 2).



,* Significant difference from baseline $p < 0.01$, and $p < 0.001$, respectively.

Figure 18 Mean and standard error of mean ($\overline{X} \pm$ SEM) of average pain, visual analogue scale (VAS) from pre-exercise, immediate, day 1 to day 14 post-exercise.

The average pain intensity of visual analogue scale was significantly increased when compared the pain level at pre-exercise to immediately post-exercise, day 1–4 ($F_{1,24}$ = 17.86, 60.90, 47.15, 28.64 and 17.73, respectively; p<0.001), day 5 ($F_{1,24}$ = 14.28, p = 0.001), and day 6 post-exercise ($F_{1,24}$ = 8.11, p = 0.009). Average pain intensity increased immediately post-exercise which peaked at day 1 (Figure 18).



,* Significant difference from baseline $p< 0.01$, and $p< 0.001$, respectively.

Figure 19 Mean and standard error of mean ($\overline{X}$ ± SEM) of muscle soreness levels using the Likert Scales as presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

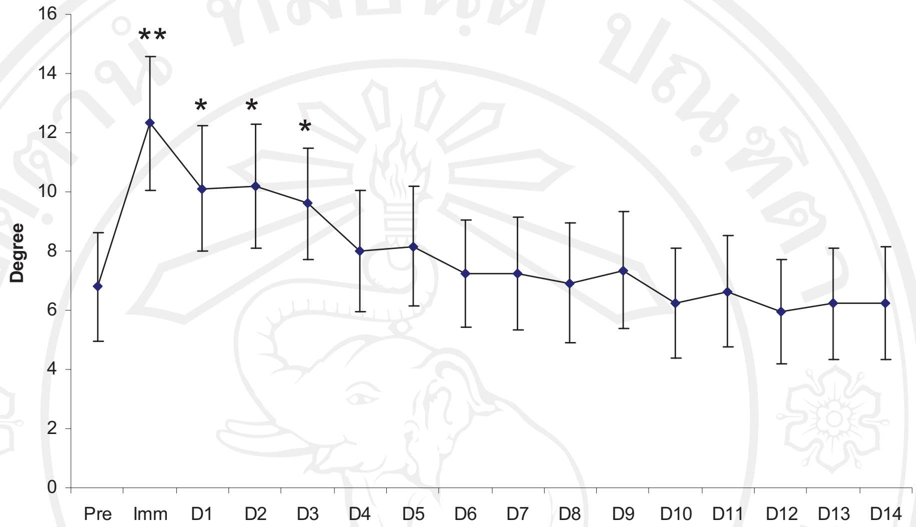
Muscle soreness level of Likert scale was significant increase immediately post-exercise, day 1 – 4 ($F_{1,24}$ = 21.07, 172.02, 109.68, 57.78 and 27.69, respectively; $p< 0.001$), day 5 ($F_{1,24}$ = 15.98, p = 0.001), and day 6 post-exercise ($F_{1,24}$ = 12.13, p = 0.002). The soreness level peaked at day 1 post-exercise (Figure 19).

4.2.2.2 Pain threshold

The result of pain threshold at origin and muscle sites demonstrated in table 2.

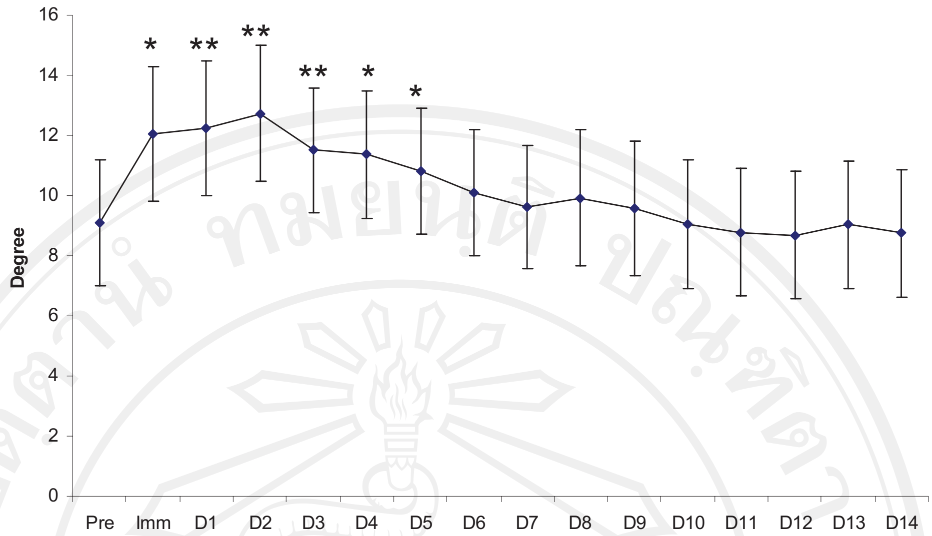
4.2.2.2.1 Thermal pain threshold

Cold pain at origin site was significantly increased when compared the data at pre-exercise to immediately post-exercise ($F_{1,24}$ = 13.50, p = 0.001), day 1 ($F_{1,24}$ = 5.19, p = 0.032), day 2 ($F_{1,24}$ = 5.74, p = 0.025), and day 3 post-exercise ($F_{1,24} = 5.60$, $p = 0.026$). Cold pain at origin site increased from pre-exercise and peaked at immediately post-exercise, it continued to elevate from day 1 to day 3 post-exercise (Figure 20).



*, ** Significant difference from baseline $p< 0.05$, and $p< 0.01$, respectively.

Figure 20 Mean and standard error of mean ($\overline{X} \pm$ SEM) of cold pain (CPT) at origin site (O) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.



*, ** Significant difference from baseline p< 0.05, and p< 0.01, respectively.

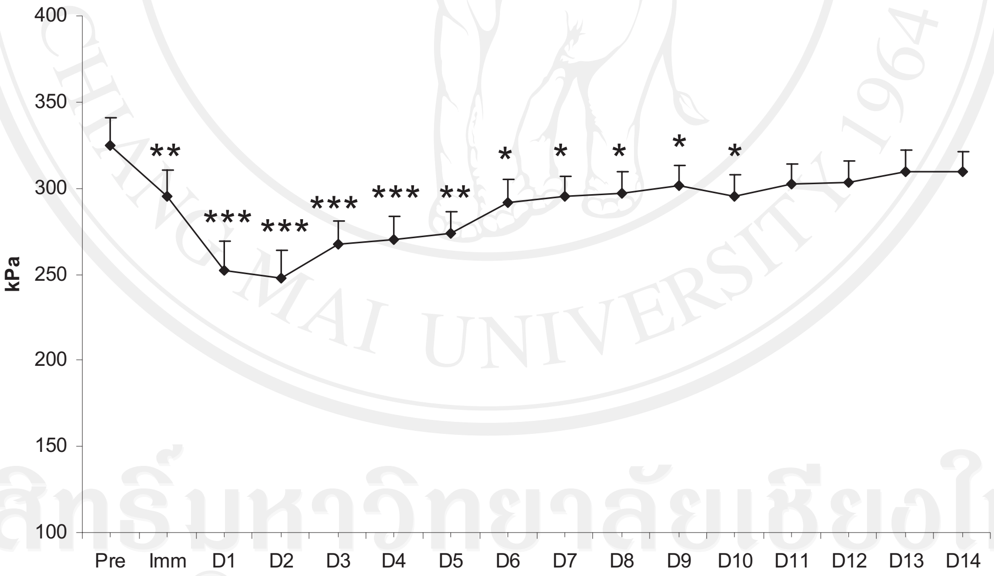
Figure 21 Mean and standard error of mean ($\overline{X} \pm$ SEM) of cold pain (CPT) at muscle site (M) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

Cold pain at muscle site was significant increase immediately post-exercise ($F_{1,24}$ = 7.23, p = 0.013), day 1 ($F_{1,24}$ = 9.15, p = 0.006), day 2 ($F_{1,24}$ = 10.21, p = 0.004), day 3 ($F_{1,24}$ = 8.79, p = 0.007), day 4 ($F_{1,24}$ = 7.16, p = 0.013), and day 5 post-exercise ($F_{1,24}$ = 6.43, p = 0.018). Cold pain at muscle site increased from pre-exercise to immediately post-exercise, it also continued to increase from day 1 to day 5, which reached the peak on the 2nd day post-exercise (Figure 21).

There was no significant difference in hot pain at the origin and muscle sites when compared the data at immediately post-exercise, day 1 - day 14 post-exercise to the baseline.

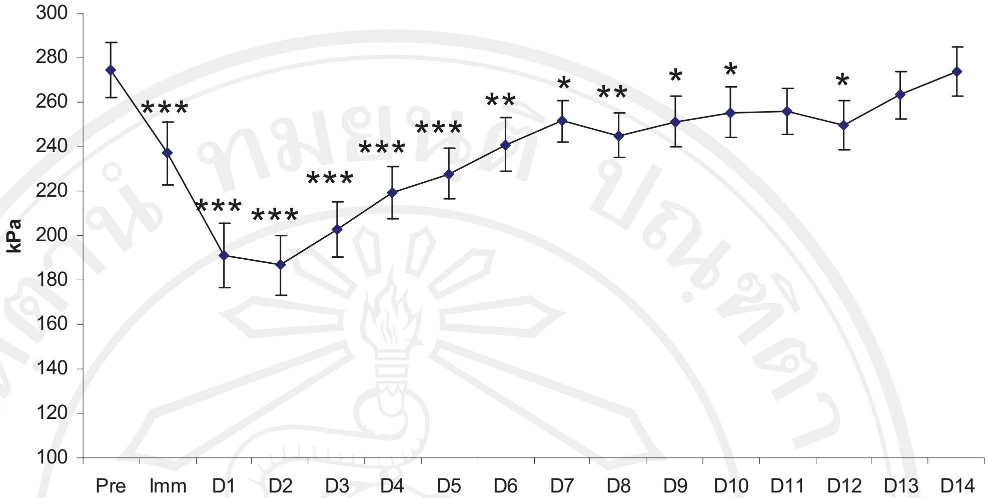
4.2.2.2.2 Mechanical pain threshold

Pressure pain threshold at origin site significantly decreased from pre-exercise when compared to an immediately post-exercise ($F_{1,24} = 9.74$, $p = 0.005$) , day 1 – 4 ($F_{1,24} = 35.33$, 28.66, 27.45, and 17.92, respectively; $p<0.001$), day 5 ($F_{1,24} = 13.53$, $p = 0.001$), day 6 ($F_{1,24} = 7.20$, $p = 0.013$), day 7 ($F_{1,24} = 5.55$, $p = 0.027$), day 8, ($F_{1,24} = 4.59$, $p = 0.043$), day 9 ($F_{1,24} = 4.39$, $p = 0.047$), and day 10 post-exercise ($F_{1,24} = 4.50$, $p = 0.044$). Pressure pain threshold decreased from pre-exercise to immediately post-exercise, continued to decrease at day 1 to day 10, and reached the lowest point on the 2nd day post-exercise (Figure 22).



*, **,*** Significant difference from baseline $p< 0.05$, $p< 0.01$, and $p< 0.001$, respectively.

Figure 22 Mean and standard error of mean ($\overline{X} \pm$ SEM) of pressure pain threshold (PPT) at origin site (O) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.



*, **,*** Significant difference from baseline $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

Figure 23 Mean and standard error of mean ($\overline{X} \pm$ SEM) of pressure pain threshold (PPT) at muscle site (M) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

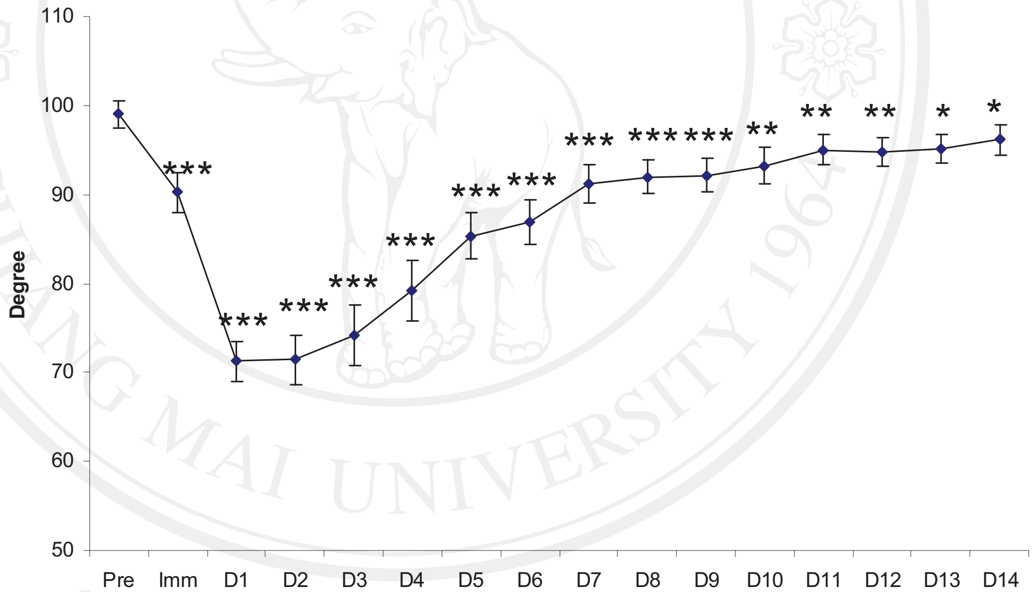
Pressure pain threshold at muscle site was significantly decreased when compared pressure pain threshold at pre-exercise to immediately post-exercise, day 1–5 ($F_{1,24}$ = 19.52, 62.68, 47.90, 32.95, 33.48, and 19.95, respectively; $p < 0.001$), day 6 ($F_{1,24} = 10.37$, $p = 0.004$), day 7 ($F_{1,24} = 6.40$, $p = 0.018$), day 8 ($F_{1,24} = 8.59$, $p = 0.007$), day 9 ($F_{1,24} = 5.13$, $p = 0.033$), day 10 ($F_{1,24} = 4.54$, $p = 0.043$) and day 12 post-exercise ($F_{1,24} = 7.97$, $p = 0.009$). Pressure pain threshold decreased from pre-exercise to immediately post-exercise, continued to decrease at day 1 to day 12 except on the day 11, and reached the lowest point on the 2^{nd} day post-exercise (Figure 23).

4.2.2.3 Vibration sense

There was no significantly different results in vibration at the origin and muscle sites when compared vibration at immediately post-exercise, day 1 - day 14 post-exercise to the baseline.

4.2.2.4 Passive range of motion

The result of range of motion in passive of flexion and extension demonstrated in table 2, figures 10 and 11.

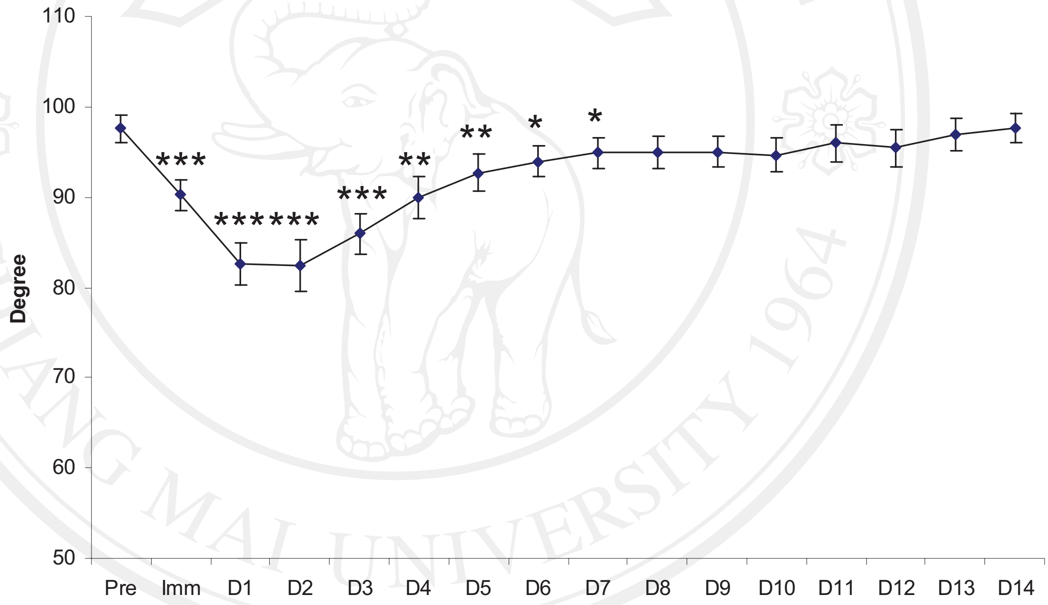


*, **,*** Significant difference from baseline $p< 0.05$, $p< 0.01$, and $p< 0.001$, respectively.

Figure 24 Mean and standard error of mean ($\overline{X} \pm$ SEM) of range of motion in passive flexion (PF) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

Range of motion in passive flexion was significantly decreased when compared the range of motion at pre-exercise to immediately post-exercise, day 1–9

($F_{1,24}$ = 16.64, 143.39, 80.25, 42.80, 27.77, 26.85, 27.66, 20.65, 20.74, and 17.89, respectively; p<0.001) , day 10 ($F_{1,24}$ = 13.25, p = 0.001), day 11 ($F_{1,24}$ = 8.54, p = 0.007), day 12 ($F_{1,24}$ = 9.65, p = 0.005), day 13 ($F_{1,24}$ = 7.34, p = 0.012), and day 14 post-exercise($F_{1,24}$ = 5.32, p = 0.016). Range of motion in passive flexion decreased from pre-exercise to immediately post-exercise, it continued to decrease from day 1 to day 14, which reached the lowest point on day 1 post-exercise (Figure 24).



*, **,*** Significant difference from baseline p< 0.05, p< 0.01, and p< 0.001, respectively.

Figure 25 Mean and standard error of mean ($\overline{X}$ ± SEM) of range of motion in passive extension (PE) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

Range of motion in passive extension was significantly decreased when compared the range of motion at pre-exercise to immediately post-exercise, day 1 –3 ($F_{1,24}$ = 22.48, 47.91, 29.04, and 29.73, respectively; p<0.001), day 4($F_{1,24}$ = 13.55,

p = 0.001), day 5 ($F_{1,24}$ = 10.78, p = 0.003), day 6 ($F_{1,24}$ = 6.71, p = 0.016), and day 7 post-exercise ($F_{1,24}$ = 4.69, p = 0.041). Range of motion in passive extension decreased from pre-exercise to immediately post-exercise, continued to decrease day 1 to day 7, which reached the lowest point on day 2 post-exercise (Figure 25).

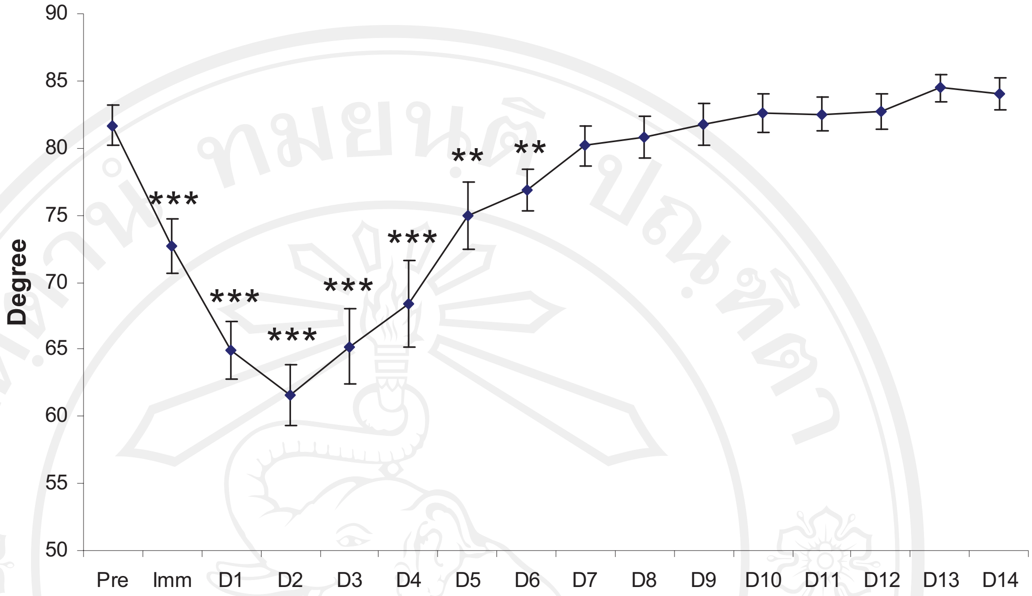
4.2.3 Motor performance

The result of motor performance including active range of motion, choice action time, grip and wrist extensor strength demonstrated in table 3.

Table 3 Mean ± SEM of the motor performance measurements.

Parameters	Pre	Imm	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14
ROM-AF	81.67±1.47	72.68±1.99 P<0.001	64.91±2.18 P<0.001	61.59±2.22 P<0.001	65.20±2.82 P<0.001	68.39±3.26 P<0.001	74.96±2.46 P=0.006	76.92±1.56 P=0.004	80.16±1.53 NS	80.83±1.58 NS	81.73±1.56 NS	82.60±1.43 NS	82.51±1.27 NS	82.73±1.31 NS	84.48±1.02 NS	84.05±1.19 NS
ROM-AE	78.60±1.35	59.84±2.27 P<0.001	62.87±2.33 P<0.001	66.04±2.26 P<0.001	69.69±1.84 P<0.001	72.77±1.75 P<0.001	75.07±1.75 P=0.002	75.48±1.54 P=0.001	77.45±1.43 NS	78.01±1.56 NS	77.51±1.56 NS	78.47±1.33 NS	79.01±1.46 NS	78.95±1.34 NS	79.56±1.29 NS	79.69±1.26 NS
CRTN	0.64±0.02	0.63±0.02 NS	0.62±0.01 P=0.025	0.62±0.01 NS	0.61±0.02 P=0.012	0.61±0.02 P=0.037	0.60±0.02 P=0.012	0.61±0.02 P=0.035	0.59±0.02 P=0.004	0.59±0.02 P=0.002	0.59±0.02 P=0.002	0.59±0.02 P=0.005	0.59±0.02 P=0.017	0.60±0.02 P=0.035	0.59±0.02 P=0.018	0.58±0.02 P=0.007
CRTD	0.66±0.02	0.70±0.02 (a) P=0.035 (b) P=0.012	0.66±0.02 NS	0.65±0.02 NS	0.64±0.02 NS	0.64±0.02 NS	0.62±0.02 P=0.014	0.64±0.02 NS	0.62±0.02 P=0.017	0.61±0.02 P=0.001	0.61±0.02 P=0.001	0.62±0.02 P=0.038	0.61±0.02 P=0.011	0.62±0.02 P=0.030	0.62±0.03 P=0.036	0.62±0.02 P=0.032
GSmax	313.30± 10.02	262.33± 10.14 P<0.001	294.82±10.70 NS	298.67± 10.36 NS	302.79±8.89 NS	314.84±10.02 NS	324.27± 10.09 NS	333.90± 11.88 P=0.21	332.09±11.27 P=0.03	339.94±11.71 P=0.004	340.65±12.64 P=0.01	337.80±11.50 P=0.02	341.18± 13.13 P=0.014	335.89± 12.89 P=0.049	342.66± 10.93 P=0.003	342.75± 12.66 P=0.007
GS pain-free	313.30± 10.02	180.88± 14.40 P<0.001	178.40±13.62 P<0.001	185.10± 15.53 P<0.001	209.74± 14.72 P<0.001	230.37±12.85 P<0.001	257.45± 12.39 P=0.001	273.98±12.27 P=0.005	274.98±13.20 P=0.009	286.49±13.25 NS	285.72±13.65 NS	291.62±13.01 NS	284.03± 13.38 P=0.029	283.70± 14.02 P=0.033	293.35± 12.57 NS	299.27± 14.86 NS
WES max	88.75±5.34	66.46±5.80 P<0.001	70.59±4.91 P=0.002	77.95±5.62 NS	84.85±5.75 NS	87.16±5.61 NS	90.52±6.17 NS	97.41±6.42 NS	90.34±15.91 NS	94.23±5.63 NS	95.00±5.78 NS	100.58±5.60 P=0.008	101.35±6.35 P=0.01	103.20± 6.52 P=0.006	100.49± 6.21 P=0.013	103.96± 7.27 P=0.01
WESpain- free	88.75±5.34	41.52±5.28 P<0.001	43.52±4.24 P<0.001	47.21±4.93 P<0.001	56.15±5.49 P<0.001	64.15±5.39 P<0.001	67.45±5.19 P<0.001	75.40±6.11 P=0.026	72.86±5.29 P=0.003	78.55±5.79 P=0.033	76.42±5.10 P=0.008	78.05±6.05 NS	78.35±5.46 P=0.021	81.09±5.59 NS	80.05±5.02 NS	79.71±5.09 NS

(a) Significant difference from baseline $p < 0.05$, (b) Significant difference between left and right sides (CRTN and CRTD) $p < 0.05$

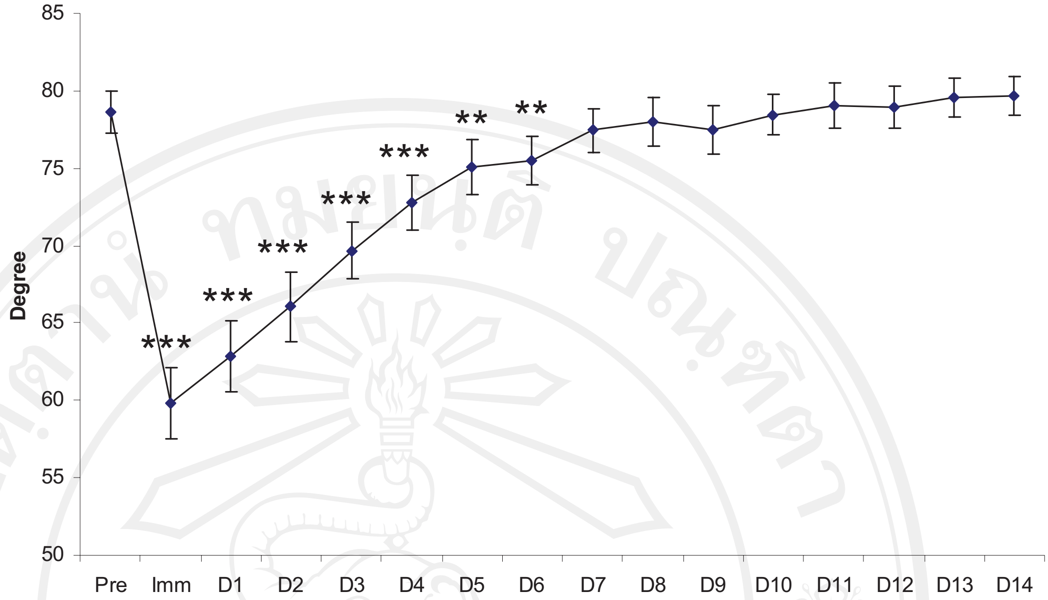


,* Significant difference from baseline $p < 0.01$, and $p < 0.001$, respectively.

Figure 26 Mean and standard error of mean ($\overline{X} \pm$ SEM) of range of motion in active flexion (AF) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

4.2.3.1 Active range of motion

Range of motion in active flexion was significantly decreased when compared the range of motion at pre-exercise to immediately post-exercise, 1 – 4 ($F_{1,24}$ = 25.65, 72.17, 91.34, 38.12, and 19.32, respectively; $p < 0.001$), day 5 ($F_{1,24}$ = 9.17, p = 0.006), and day 6 post-exercise ($F_{1,24}$ = 10.40, p = 0.004). Range of motion in active flexion decreased from pre-exercise to immediately post-exercise, continued to decrease day 1 to day 6, and reached the lowest point on the day 2 post-exercise (Figure 26).



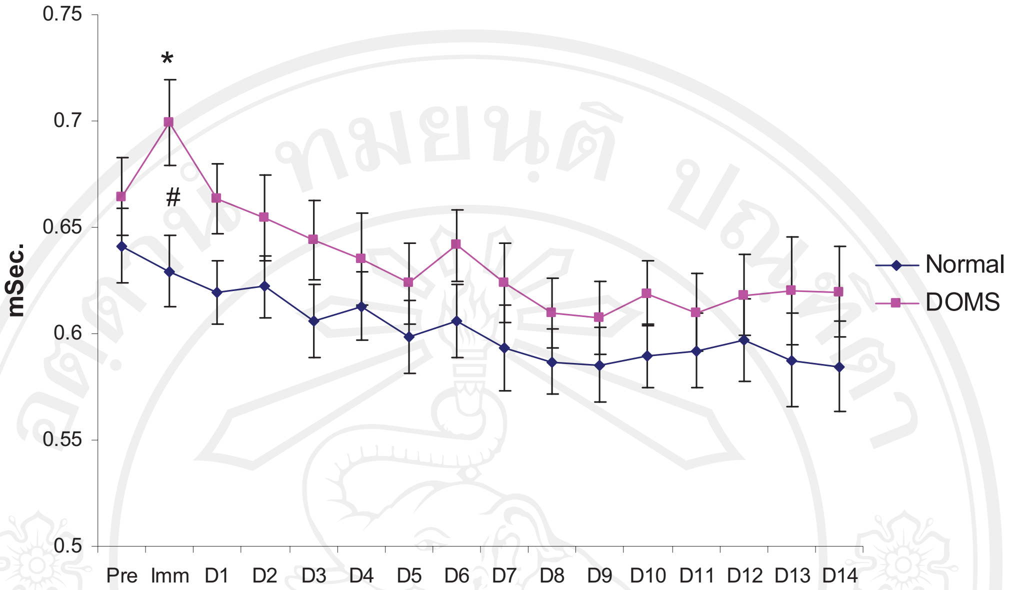
,* Significant difference from baseline $p< 0.01$, and $p< 0.001$, respectively.

Figure 27 Mean and standard error of mean ($\overline{X} \pm$ SEM) of range of motion in active extension (AE) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

Range of motion in active extension was significantly decreased when compared the range of motion at pre-exercise to immediately post-exercise, day 1–4 ($F_{1,24}$ = 115.40, 60.45, 45.91, 35.64, and 18.05, respectively; $p< 0.001$), day 5 ($F_{1,24}$ = 11.62, p = 0.002), day 6 post-exercise ($F_{1,24}$ = 15.83, p = 0.001). Range of motion in active extension decreased from pre-exercise to the lowest point at immediately post-exercise, it continued to decrease from day 1 to day 6 post-exercise (Figure 27).

4.2.3.2 Choice response time

Choice response time in DOMS side was significantly increased when compared the response time at pre-exercise to immediately post-exercise ($F_{1,24}$ = 4.99, p = 0.035). It was increased from the baseline to 0.699 ± 0.02 mSec which was significantly greater than the normal side ($F_{1,24}$ = 7.34, p = 0.012). In addition, on both sides also showed the trend of reduction in choice response time (Figure 28).



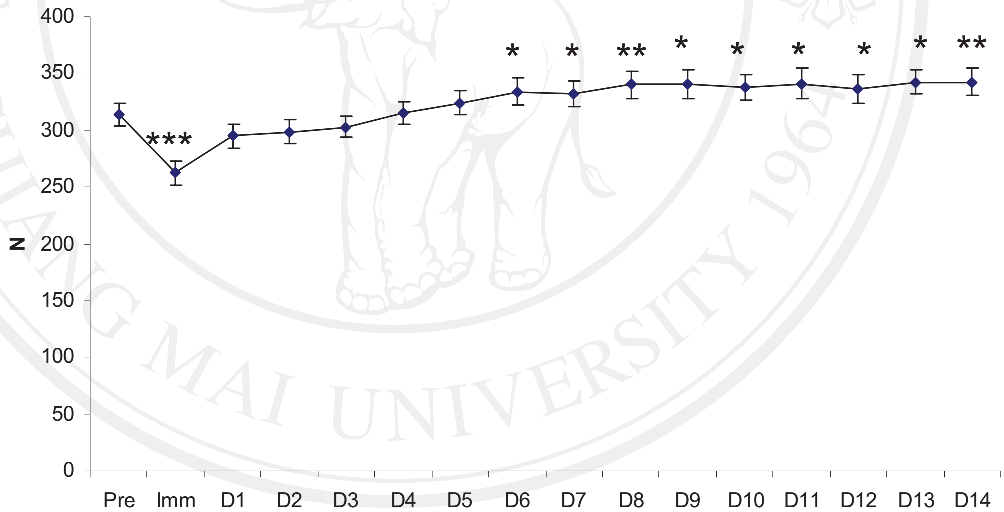
* Significant difference from baseline $p < 0.05$

Significant difference between groups $p < 0.05$

Figure 28 Mean and standard error of mean ($\overline{X}$ ± SEM) of choice response time (CRT) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise in DOMS and normal sides.

4.2.3.3 Muscle strength

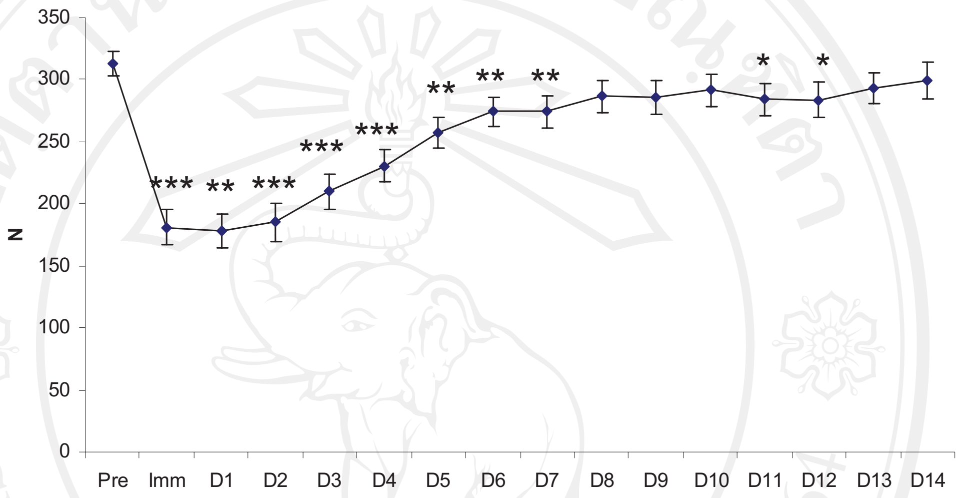
Maximal grip strength was significantly decreased only when compared the data at pre-exercise to immediately post-exercise ($F_{1,24}$ = 34.16, p<0.001). Maximal GS was significantly increased when compared GS at pre-exercise to day 6-14 post-exercise ($F_{1,24}$ = 6.15, p <0.021; $F_{1,24}$ = 5.35, p <0.03; $F_{1,24}$ = 10.29, p <0.004; $F_{1,24}$ = 7.77, p <0.01; $F_{1,24}$ = 6.16, p <0.02; $F_{1,24}$ = 6.98, p <0.014; $F_{1,24}$ = 4.32, p <0.049; $F_{1,24}$ = 10.40, p <0.003, and $F_{1,24}$ = 8.58, p <0.007, respectively) (Figure 29).



*, **,*** Significant difference from baseline p< 0.05, p< 0.01, and p< 0.001, respectively.

Figure 29 Mean and standard error of mean ($\overline{X}$ ± SEM) of maximal grip strength (GS) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

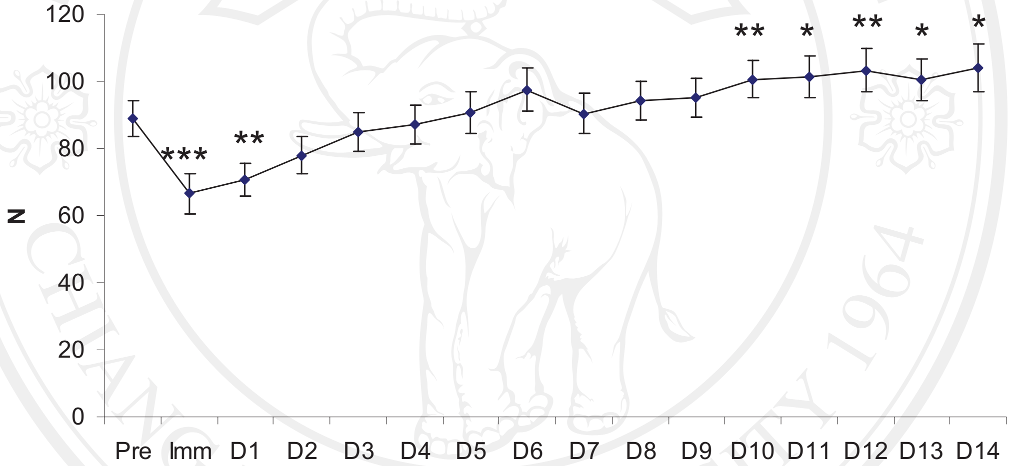
Pain-free grip strength was significantly decreased when compared at pre-exercise to immediately post-exercise, day 1–4 ($F_{1,24}$ = 187.69, 108.20, 74.19, 48.26, and 37.25, respectively; p< 0.001), day 5 ($F_{1,24}$ = 14.33, p = 0.001), day 6 ($F_{1,24}$ = 9.71, p = 0.005), day 7($F_{1,24}$ = 8.04, p = 0.009), day 11 ($F_{1,24}$ = 5.40, p = 0.029), and 12 post-exercise ($F_{1,24} = 5.12$, $p = 0.033$). The pain-free force exerted decreased from pre-exercise to immediately post-exercise, it continued to decrease at day 1 to day 7 and day 11-12, which reached the lowest point on day 1 post-exercise (Figure 30).



*, **,*** Significant difference from baseline $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

Figure 30 Mean and standard error of mean ($\overline{X} \pm$ SEM) of pain-free grip strength (GS pain-free) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

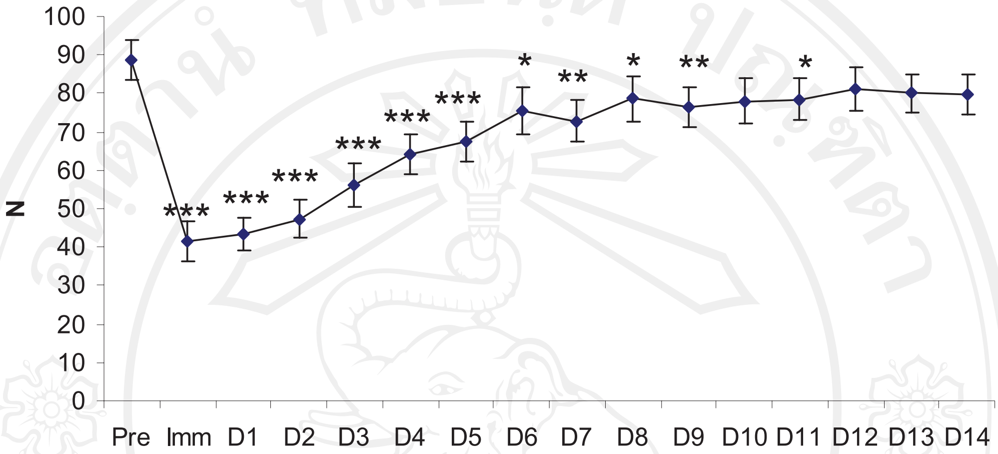
Maximal wrist extensor strength was significantly decreased when compared the data at pre-exercise to immediately post-exercise ($F_{1,24} = 21.22$, $p < 0.001$), and day 1 post-exercise ($F_{1,24} = 12.07$, $p = 0.002$). Maximal WES was significantly increased when compared to WES at pre-exercise to day 10 ($F_{1,24} = 8.32$, $p = 0.008$), day 11 ($F_{1,24} = 7.85$, $p = 0.01$), day 12 ($F_{1,24} = 8.93$, $p = 0.006$), day 13 ($F_{1,24} = 7.21$, $p = 0.013$), day 14 post-exercise ($F_{1,24} = 7.81$, $p = 0.01$) (Figure 31)



*, **,*** Significant difference from baseline $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

Figure 31 Mean and standard error of mean ($\overline{X} \pm$ SEM) of maximal wrist extensor strength (WES) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

Pain-free WES was significantly decreased when compared the pre-exercise to immediately post-exercise, day 1–5 ($F_{1,24}$ = 88.56, 57.88, 41.68, 27.74, 31.99 and 21.14, respectively; $p<0.001$), day 6 ($F_{1,24} = 5.63$, $p = 0.026$), day 7 ($F_{1,24} = 10.89$, $p = 0.003$), day 8 ($F_{1,24} = 5.11$, $p = 0.033$), day 9 ($F_{1,24} = 8.40$, $p = 0.008$), and day 11 post-exercise ($F_{1,24} = 6.14$, $p = 0.021$). The pain-free force exerted decreased from pre-exercise to the lowest point at immediately post-exercise, it continued to decrease at day 1 to day 11 excepted on day 10 post-exercise (Figure 32).



*,**,*** Significant difference from baseline *p*< 0.05, *p*< 0.01, and *p*< 0.001, respectively.

Figure 32 Mean and standard error of mean ($\overline{X}$ ± SEM) of pain-free wrist extensor strength (WES pain-free) presenting from pre-exercise, immediate, day 1 to day 14 post-exercise.

There were some notable relationships among the measurement outcomes during the most painful day post exercise (i.e., D1, D2) these additional data were presents in appendix 6.

4.3 The prophylactic effect of physical interventions on DOMS

Regarding to the study of DOMS characteristics, the sensitive outcome measures were selected in the preventative study including pain intensity, pain threshold (CPT and PPT) at the muscle site, ROM, and muscle strength.

4.3.1 A prophylactic effect of proprioceptive neuromuscular facilitation (PNF) stretching on DOMS

Sample characteristics showed in the mean age, height, and weight. No significant difference was seen in the mean age, height, and weight between groups. All subjects were able to complete each set of the exercise induction protocol. No significant differences in mean maximal torque and total work during the eccentric exercise were evident between the control and PNF groups (Table 4).

Table 4 Mean and standard deviation ($\overline{X} \pm SD$) of subject's characteristics (age, height, and weight) and work load during eccentric-exercise induction in control and PNF groups.

Characteristics	Control group (N = 14)	PNF group (N = 14)
Age (years)	21.07 ± 1.59	20.50 ± 0.94
Height (cm)	173.14 ± 5.14	173.00 ± 4.45
Weight (kg)	61.29 ± 9.55	62.43 ± 7.57
Peak Torque (N)	3.25 ± 0.87	4.01 ± 1.41
Total Work (J)	180.03 ± 56.61	177.19 ± 59.99

No significant difference between groups were evident for all data

4.3.1.1 Blood flow before and after PNF application

No significant differences in blood flow measuring before PNF (12.55 ± 5.89 flux/ min) and after PNF applications (14.16 ± 6.05 flux/min).

4.3.1.2 Baseline measures

No significant ($p \geq$ 0.117) differences in the baseline values between groups were observed for any of the dependent variables except for PPT. Therefore, normalized data were used to adjust a variation among individual subjects.

4.3.1.3 Pain intensity

Muscle soreness developed immediately after exercise, peaked 1-2 days post exercise, and disappeared within a week for both groups. The changes in muscle soreness were not significantly different between control and PNF groups for VAS (p = 0.871) (Figure 33) and LS (p = 0.140) (Figure 34).

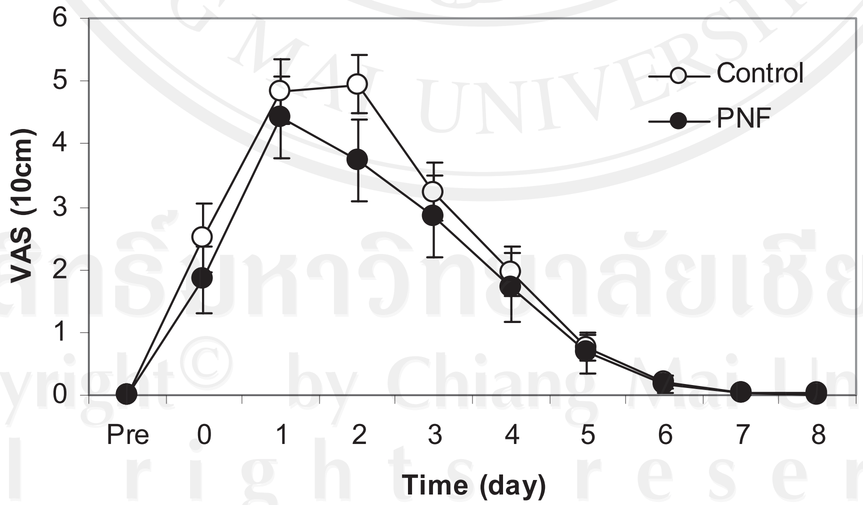


Figure 33 Mean and standard error of mean ($\overline{X}$ ± SEM) of average pain, visual analogue scale (VAS) from pre-exercise (Pre), immediate after (0), 1–8 days following eccentric exercise for the PNF and control groups.

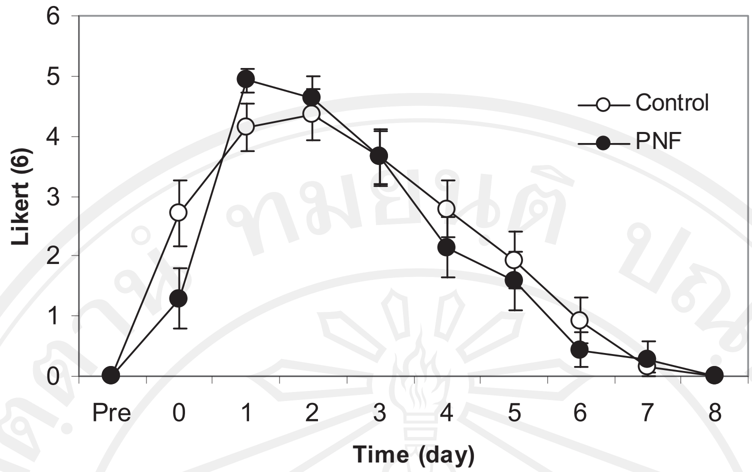


Figure 34 Mean and standard error of mean ($\overline{X} \pm$ SEM) of average pain, Likert's scale (LS) from pre-exercise (Pre), immediate after (0), 1–8 days following eccentric exercise for the PNF and control groups.

4.3.1.4 Thermal pain threshold

Significant difference in the changes of cold thermal pain threshold was evident between groups (p = 0.002). The PNF group significantly demonstrated a lesser deficit ($p \leq$ 0.043) in cold thermal pain threshold than the control group on days 1-5 post-exercise (Figure 35).

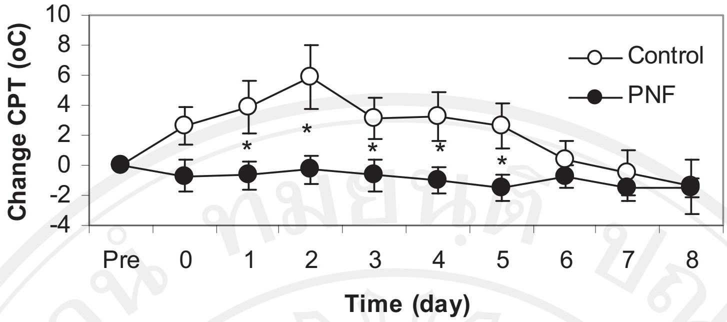


Figure 35 Relative changes in cold thermal pain threshold (CPT) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the PNF and control groups. Mean and standard error ($\overline{X}$ ± SEM) are shown for each group. *: significantly different between groups (p< 0.05).

4.3.1.5 Pressure pain threshold

The changes in PPT was not significantly different between control and PNF groups for this outcome measure (p = 0.480).

4.3.1.6 Range of motion

The decreases in passive flexion (PF), passive extension (PE), active flexion (AF) and active extension (AE) were significantly (PF: p = 0.020, PE: p = 0.001, AF: p = 0.043, AE: p = 0.004) smaller for the PNF group compared with the control group. The PNF group significantly demonstrated a lesser deficit in ROM-PF than the control group on day 1 post-exercise (p = 0.028). ROM-PF was significantly decreased when comparing the range at pre-exercise to days 1-5 post-exercise in the control group ($p \leq$ 0.011) and ROM-PF was significantly decreased when comparing the range at pre-exercise to days 1-4 post-exercise in the PNF group ($p \leq$ 0.033) (Figure 36).

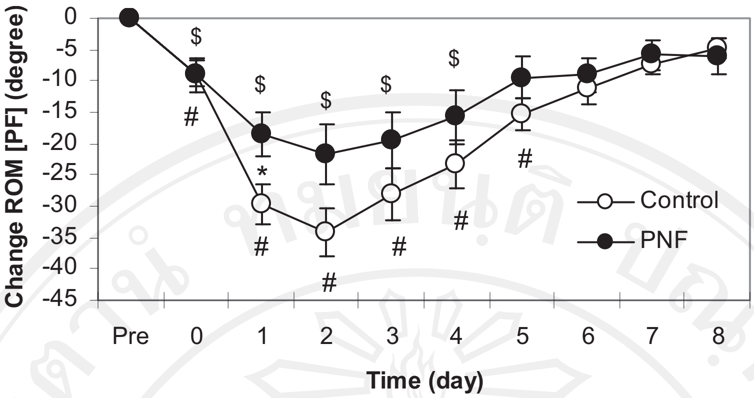


Figure 36 Relative changes in passive flexion range of motion (ROM-PF) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the PNF and control groups. Mean and standard error ($\overline{X} \pm$ SEM) are shown for each group. #: significantly different from the baseline in control group ($p< 0.05$), $: significantly different from the baseline in PNF group ($p< 0.05$),*: significantly different between groups ($p< 0.05$).

The PNF group significantly demonstrated a lesser deficit in ROM-PE than the control group on immediately post-exercise and days 1-8 post-exercise ($p\leq 0.049$). ROM-PE was significantly decreased when comparing the range at pre-exercise to days 1-3 post-exercise ($p\leq 0.01$) in control group. However, ROM-PE in the PNF group was not significantly difference from the baseline ($p = 0.077$) (Figure 37).

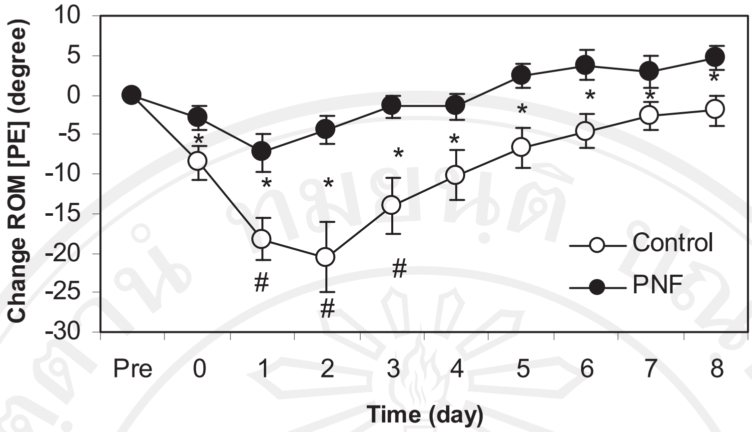


Figure 37 Relative changes in passive extension range of motion (ROM-PE) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the PNF and control groups. Mean and standard error ($\overline{X} \pm$ SEM) are shown for each group. #: significantly different from the baseline in control group ($p< 0.05$), *: significantly different between groups ($p< 0.05$).

ROM-AF was significantly decreased when comparing the range at pre-exercise to days 1-4 post-exercise ($p\leq 0.006$) in control group, and ROM-AF was significantly decreased when comparing the range at pre-exercise to days 2-3 post-exercise ($p\leq 0.002$) in the PNF group, but no difference between groups.

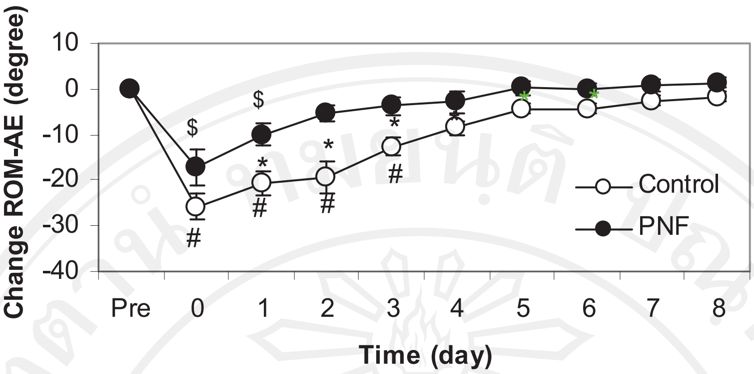


Figure 38 Relative changes in active extension range of motion (ROM-AE) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the PNF and control groups. Mean and standard error ($\overline{X}$ ± SEM) are shown for each group. #: significantly different from the baseline in control group (p< 0.05), $: significantly different from the baseline in PNF group (p< 0.05),*: significantly different between groups (p< 0.05).

The PNF group also significantly demonstrated a lesser deficit in ROM-AE than the control group on days 1-6 post-exercise ($p \leq$ 0.048). ROM-AE was significantly decreased from the baseline during an immediately post-exercise and days 1-3 post-exercise ($p \leq$ 0.001) in the control group, and the ROM-AE of the PNF group decreased significantly from an immediately post-exercise and day 1 post-exercise ($p \leq$ 0.017) (Figure 38).

4.3.1.7 Muscle strength

The decreases in pain-free grip strength and pain-free wrist extensor strength were significantly (GS [pain-free]: p = 0.019, WES [pain-free]: p = 0.000) smaller for the PNF group compared with the control group. Pain-free grip strength declined significantly from the baseline during an immediately post-exercise and days 1-2 post-exercise ($p \leq 0.003$) in the PNF group; however, the GS [pain-free] of the control group decreased significantly from an immediate post-exercise and did not return to the pre-exercise level by 3 days post-exercise ($p \leq 0.002$). The PNF group significantly demonstrated a lesser deficit in GS [pain-free] than the control group on day 2 post-exercise ($p = 0.002$) (Figure 39). There was no significant difference in GS [max] between control and PNF groups. Pain-free wrist extensor strength declined significantly from the baseline during an immediately post-exercise and days 1-4 post-exercise ($p \leq 0.012$) in the PNF group; however, the WES [pain-free] of the control group decreased significantly from an immediate post-exercise and did not return to the pre-exercise level by 5 days post-exercise ($p \leq 0.048$). The PNF group significantly demonstrated a lesser deficit in WES [pain-free] than that of the control group on days 1-2 and day 5 post-exercise ($p \leq 0.037$) (Figure 40). There was no significant difference in WES [max] between control and PNF groups.

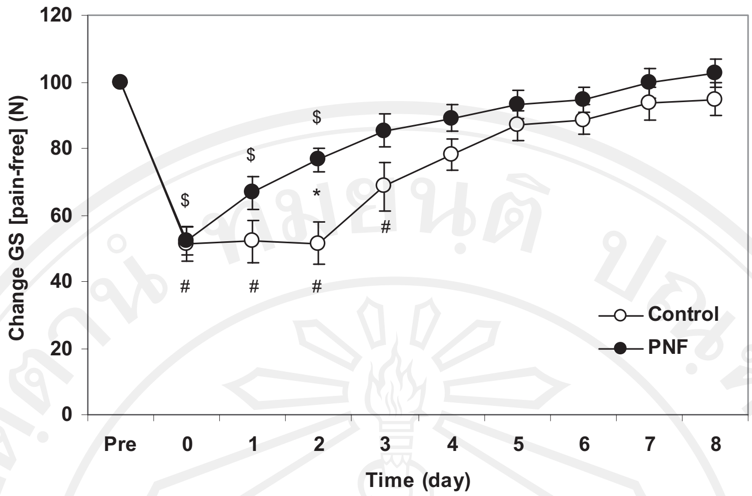


Figure 39 Normalized changes in grip strength with pain-free (GS pain-free) from the baseline (Pre: 100%), immediately after (0), and 1–8 days following eccentric exercise for the PNF and control groups. Mean and standard error ($\overline{X}$ ± SEM) are shown for each group. #: significantly different from the baseline in control group (p< 0.05), $: significantly different from the baseline in PNF group (p< 0.05), *: significantly different between groups (p< 0.05).

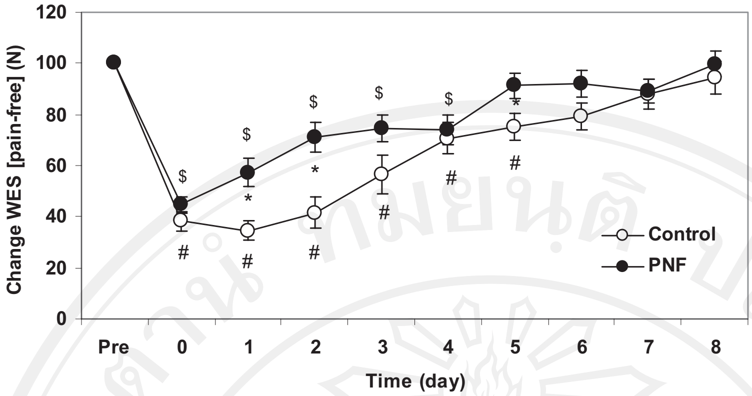


Figure 40 Normalized changes in wrist extensor strength with pain-free (WES pain-free) from the baseline (Pre: 100%), immediately after (0), and 1–8 days following eccentric exercise for the PNF and control groups. Mean and standard error ($\overline{X}$ ± SEM) are shown for each group. #: significantly different from the baseline in control group (*p*< 0.05), $: significantly different from the baseline in PNF group (*p*< 0.05), *: significantly different between groups (*p*< 0.05).

4.3.2 A Prophylactic Effect of Massage on DOMS

Characteristics of the studied volunteers were showed in the table 5, including mean age, height, and weight. No significant difference was seen in the mean age, height, and weight between groups. All subjects were able to complete each set of the exercise induction protocol. No significant differences in mean maximal torque and total work during the eccentric exercise were evident between the control and massage groups (Table 5).

Table 5 Mean and standard deviation ($\overline{X} \pm SD$) of subject's characteristics (age, height, and weight) and work load during eccentric-exercise induction in control and massage group.

Characteristics	Control group (N = 14)	Massage group (N = 14)
Age (years)	21.07 ± 1.59	20.50 ± 0.65
Height (cm)	173.14 ± 5.14	169.36 ± 6.05
Weight (kg)	61.29 ± 9.55	58.79 ± 8.83
Peak Torque (N)	3.25 ± 0.87	3.88 ± 1.18
Total Work (J)	180.03 ± 56.61	177.71 ± 67.76

No significant difference between groups were evident for all data

4.3.2.1 Blood flow before and after massage application

There was significantly increased in blood flow measuring before massage (10.47 ± 2.55 flux/ min) and after massage applications (48.24 ± 26.51 flux/min) ($p< 0.001$).

4.3.2.2 Baseline measures

No significant ($p\geq$ 0.072) differences in the baseline values between groups were observed for any of the dependent variables except for PPT. Therefore normalized data were applied to adjust a variation among individual subjects.

4.3.2.3 Pain intensity

Muscle soreness developed immediately after exercise, peaked 1-2 days post exercise, and disappeared within a week for both groups. The changes in muscle soreness were not significantly different between control and massage groups for VAS (p = 0.899) (Figure 41) and LS (p = 0.137) (Figure 42).

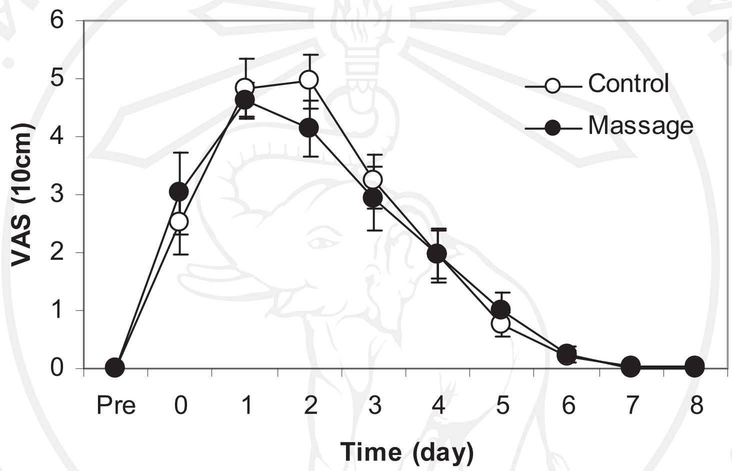


Figure 41 Mean and standard error of mean ($\overline{X}$ ± SEM) of average pain, visual analogue scale (VAS) from pre-exercise (Pre), immediate after (0), 1–8 days following eccentric exercise for the massage and control groups.

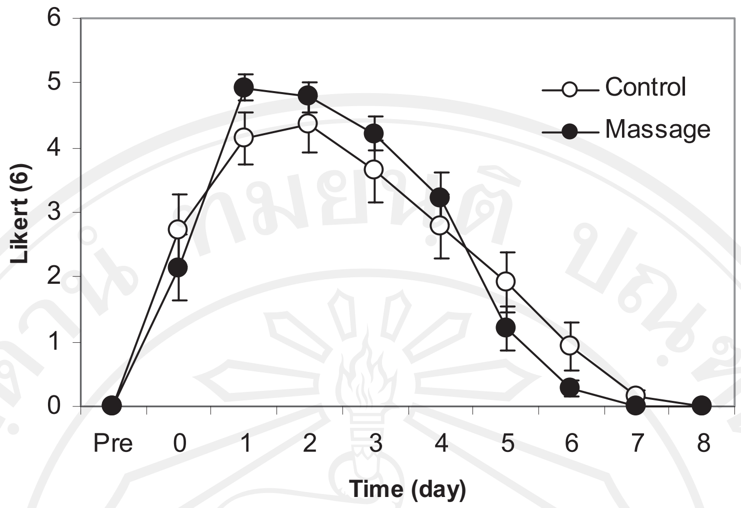


Figure 42 Mean and standard error of mean ($\overline{X}$ ± SEM) of average pain, Likert's scale (LS) from pre-exercise (Pre), immediate after (0), 1–8 days following eccentric exercise for the massage and control groups.

4.3.2.4 Thermal pain threshold

No significant (p = 0.064) difference in the changes of thermal pain threshold was evident between groups.

4.3.2.5 Pressure pain threshold

The changes in PPT was not significantly different between control and massage groups for this outcome measure (p = 0.332).

4.3.2.6 Range of motion

The decreases in passive flexion (PF), passive extension (PE) and active flexion were significantly (ROM-PF: p = 0.004, ROM-PE: p = 0.000 and ROM-AF: p = 0.028) smaller for the massage group compared with the control group. The massage group significantly demonstrated a lesser deficit in ROM-PF than the control group on day 2 post-exercise (p = 0.042), and in massage group also demonstrated a lesser deficit in ROM-PE than the control group significantly on days 1, 2, and 4 post-exercise ($p \leq 0.02$). ROM-PF was significantly decreased when comparing the range at pre-exercise to days 1-5 post-exercise in the control group ($p \leq 0.011$) and in the massage group ($p \leq 0.041$) (Figure 43). ROM-PE was significantly decreased when comparing the range at pre-exercise to days 1-3 post-exercise ($p \leq 0.01$) in control group. However, ROM-PE in the massage group was not significantly difference from the baseline (p = 0.05) (Figure 44). ROM-AF was significantly decreased when comparing the range at pre-exercise to days 1-4 post-exercise ($p \leq 0.006$) in control group and in the massage group ($p \leq 0.041$). However, no significant difference between group was evident for active ROM (Figure 45).

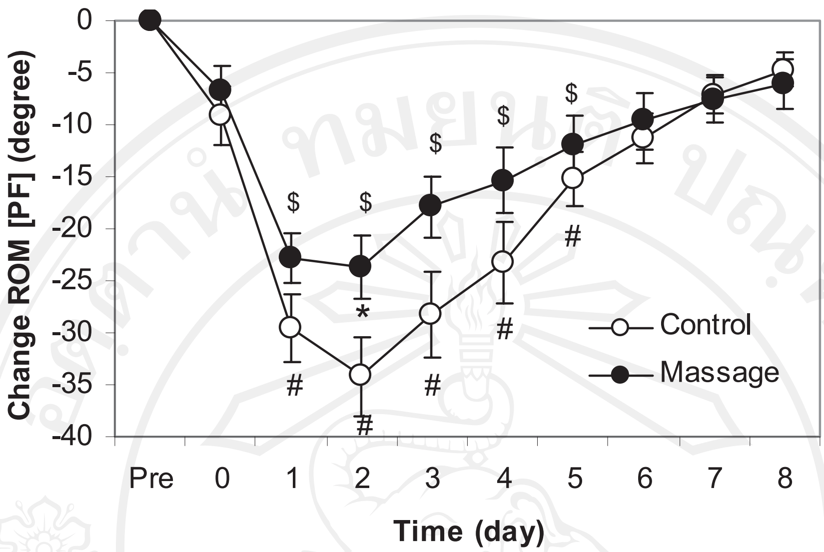


Figure 43 Relative changes in range of motion in passive flexion (PF) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the massage and control groups. Mean and standard error of mean ($\overline{X} \pm$ SEM) are shown for each group. #: significantly different from the baseline in control group ($p< 0.05$), $: significantly different from the baseline in massage group ($p< 0.05$), *: significantly different between groups ($p< 0.05$).

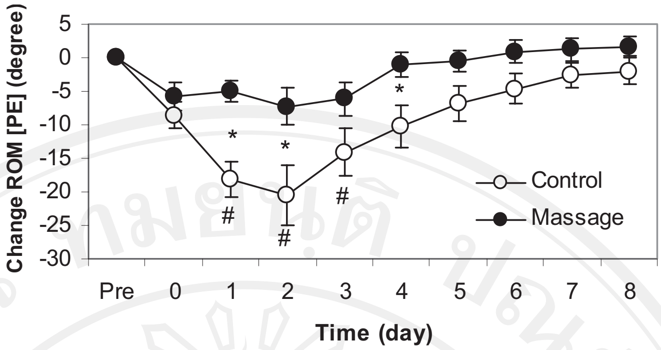


Figure 44 Relative changes in range of motion in passive extension (PE) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the massage and control groups. Mean and standard error of mean ($\overline{X} \pm$ SEM) are shown for each group. #: significantly different from the baseline in control group (p< 0.05), *: significantly different between groups (p< 0.05).

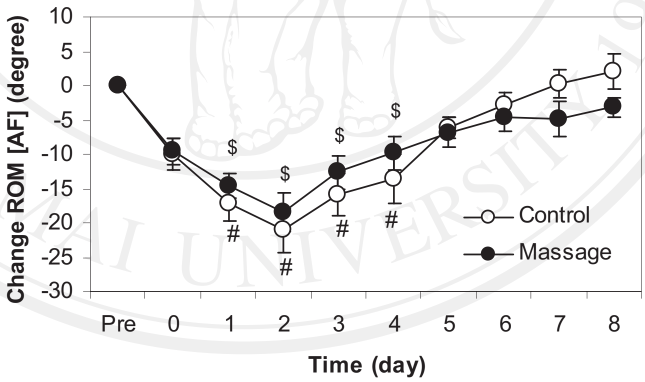


Figure 45 Relative changes in range of motion in active flexion (AF) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the massage and control groups. Mean and standard error of mean ($\overline{X} \pm$ SEM) are shown for each group. #: significantly different from the baseline in control group (p< 0.05), $: significantly different from the baseline in massage group (p< 0.05).

4.3.2.7 Muscle strength

Both pain-free grip and wrist extension strength decreased significantly ($p < 0.001$) following exercise; and no significant differences between groups were evident for changes in pain-free GS ($p = 0.342$) and WES ($p = 0.303$). Maximal grip and wrist extensor strength also showed a similar result as the pain-free strength.

4.3.3 A prophylactic effect of hot pack on DOMS

Characteristics of the subjects in this study showed in the mean age, height, and weight. No significant difference was seen in the mean age, height, and weight between groups. All subjects were able to complete each set of the exercise induction protocol. No significant differences in mean maximal torque and total work during the eccentric exercise were evident between the control and hot pack groups (Table 6).

Table 6 Mean and standard deviation ($\overline{X} \pm SD$) of subject's characteristics (age, height, and weight) and work load during eccentric-exercise induction in control and hot pack group.

Characteristics	Control group (N = 14)	Hot pack group (N = 14)
Age (years)	21.07 ± 1.59	20.43 ± 1.02
Height (cm)	173.14 ± 5.14	169.00 ± 5.56
Weight (kg)	61.29 ± 9.55	69.29 ± 19.71
Peak Torque (N)	3.25 ± 0.87	4.36 ± 1.69
Total Work (J)	180.03 ± 56.61	223.88 ± 117.50

No significant difference between groups were evident for all data

4.3.3.1 Skin temperature and skin blood flow

The skin temperature over the extensor carpi radialis brevis increased significantly ($p < 0.001$) from baseline (31.64 ± 0.85°C) to 42.87 ± 0.60°C after hot pack application. The skin blood flow at the belly of forearm extensor muscles also increased significantly ($p < 0.001$) from pre- hot pack application (12.56 ± 6.68 flux/min) to post-hot pack application (91.72 ± 54.04 flux/min).

4.3.3.2 Baseline measures

No significant ($p \geq 0.099$) differences in the baseline values between groups were observed for any of the dependent variables except for PPT. Normalized data were also used to adjust a variation among individual subjects.

4.3.3.3 Pain intensity

Muscle soreness developed immediately after exercise, peaked 1-2 days post-exercise, and disappeared within a week for both groups. The changes in muscle soreness were not significantly different between control and hot pack groups for VAS (p = 0.698) (Figure 46) and modified Likert's scale (p = 0.222) (Figure 47).

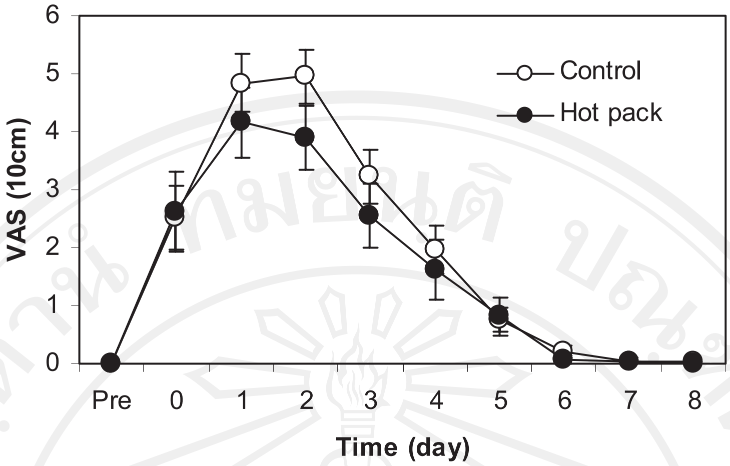


Figure 46 Mean and standard error of mean ($\overline{X}$ ± SEM) of average pain, visual analogue scale (VAS) from pre-exercise (Pre), immediate after (0), 1 – 8 days following eccentric exercise for the hot pack and control groups.

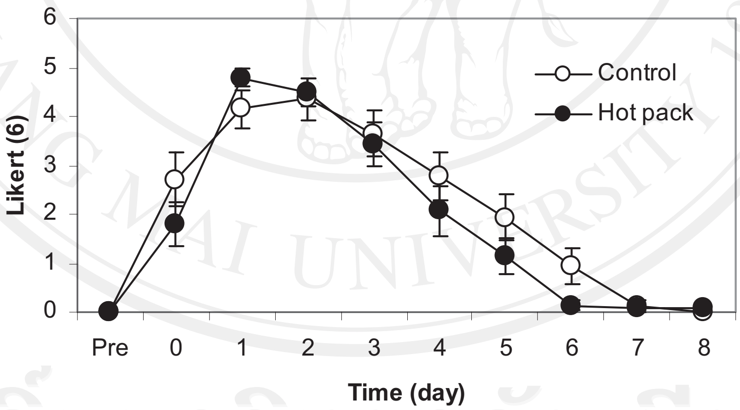


Figure 47 Mean and standard error of mean ($\overline{X}$ ± SEM) of average pain, Likert's scale (LS) from pre-exercise (Pre), immediate after (0), 1 – 8 days following eccentric exercise for the hot pack and control groups.

4.3.3.4 Cold thermal pain threshold (CPT)

No significant (p = 0.192) difference in the changes was evident between groups.

4.3.3.5 Pressure pain threshold (PPT)

PPT decreased significantly after exercise, but the decreases were significantly smaller for the hot pack than the control group (p = 0.026) as shown in Figure x. PPT was significantly decreased from the baseline during days 1-2 post-exercise ($p \leq$ 0.030) in the hot pack group; however, the PPT of the control group decreased significantly from the first post-exercise and did not return to the pre-exercise level by 3 days post-exercise ($p \leq$ 0.003). The hot pack group was significantly higher in PPT than the control group on day 3 post-exercise (p = 0.041) (Figure 48).

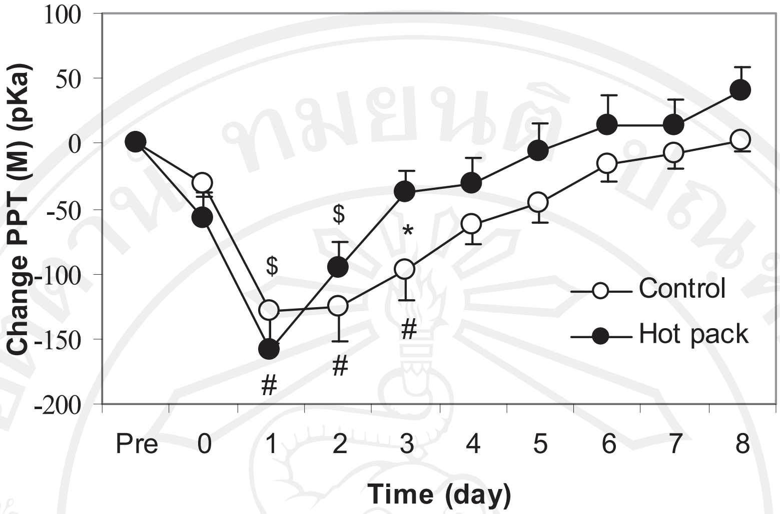


Figure 48 Relative changes in pressure pain threshold (PPT) from the baseline (Pre), immediately after (0), and 1–8 days following eccentric exercise for the hot pack and control groups. Mean and standard error ($\overline{X} \pm$ SEM) are shown for each group. #: significantly different from the baseline in control group ($p < 0.05$), $: significantly different from the baseline in hot pack group ($p < 0.05$), *: significantly different between groups ($p < 0.05$).

4.3.3.6 Range of motion (ROM)

Figures 49 and 50 show changes in passive ROM for flexion and extension. Figure 51 shows changes in active ROM for extension. The decreases in passive flexion (PF), passive extension (PE), and active extension (AE) were significantly (PF: $p = 0.002$, PE: $p = 0.007$, and AE: $p < 0.001$) smaller for the hot pack group compared with the control group; however, no significant ($p = 0.593$) difference between groups was evident for active flexion. The hot pack group significantly demonstrated a lesser deficit in ROM-PF than the control group on days

1-8 post-exercise (p = 0.040). ROM-PF was significantly decreased when comparing the range at pre-exercise to days 1-5 post-exercise in the control group ($p \leq 0.011$) and ROM-PF was significantly decreased when comparing the range at pre-exercise to days 1-3 post-exercise in the hot pack group ($p \leq 0.018$) (Figure 49). The hot pack group significantly demonstrated a lesser deficit in ROM-PE than the control group on days 2-3 post-exercise ($p \leq 0.032$). ROM-PE was significantly decreased when comparing the range at pre-exercise to days 1-3 post-exercise ($p \leq 0.01$) in control group and ROM-PE was significantly decreased when comparing the range at pre-exercise to day 1 post-exercise in the hot pack group ($p \leq 0.014$) (Figure 50). The hot pack group also significantly demonstrated a lesser deficit in ROM-AE than the control group on days 1-4 post-exercise ($p \leq 0.023$). ROM-AE was significantly decreased from the baseline during an immediately post-exercise and days 1-3 post-exercise ($p \leq 0.001$) in the control group, and the ROM-AE of the hot pack group decreased significantly from an immediately post-exercise and day 1 post-exercise ($p \leq 0.009$) (Figure 51).

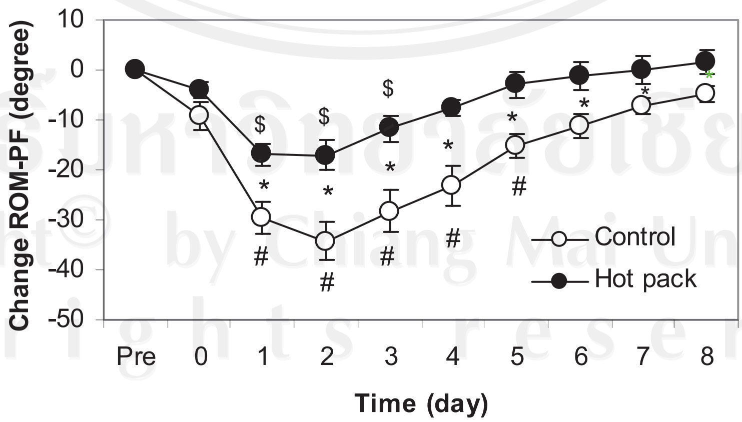


Figure 49 Relative changes in passive flexion range of motion (ROM-PF) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise

for the hot pack and control groups. Mean and standard error ($\overline{X}$ ± SEM) are shown for each group. #: significantly different from the baseline in control group (*p*< 0.05), $: significantly different from the baseline in hot pack group (p< 0.05),*: significantly different between groups (*p*< 0.05).

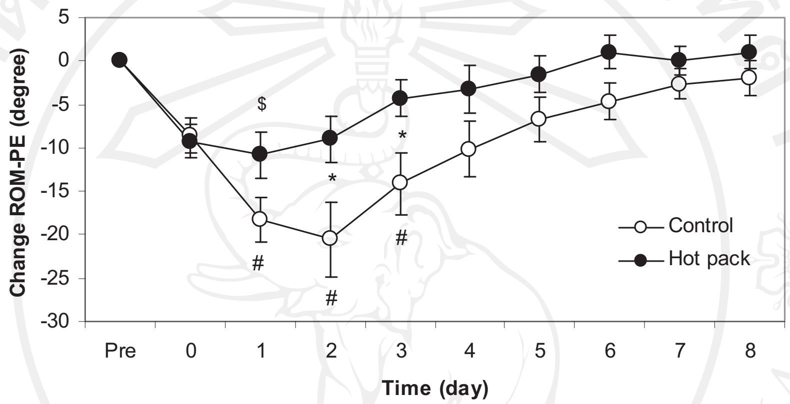


Figure 50 Relative changes in passive extension range of motion (ROM-PE) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the hot pack and control groups. Mean and standard error ($\overline{X}$ ± SEM) are shown for each group. #: significantly different from the baseline in control group (*p*< 0.05), $: significantly different from the baseline in hot pack group (p< 0.05),*: significantly different between groups (*p*< 0.05).

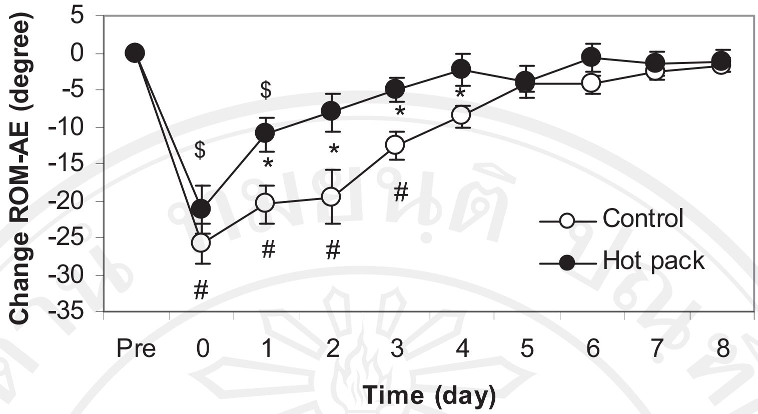


Figure 51 Relative changes in active extension range of motion (ROM-AE) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the hot pack and control groups. Mean and standard error ($\overline{X}$ ± SEM) are shown for each group. #: significantly different from the baseline in control group ($p < 0.05$), $: significantly different from the baseline in hot pack group ($p < 0.05$),*: significantly different between groups ($p < 0.05$).

4.3.3.7 Muscle strength

No significant differences between groups were evident for changes in maximal grip strength ($P = 0.601$), pain-free grip strength ($P = 0.121$), and maximal wrist extensor strength ($P = 0.167$). However, Pain-free wrist extensor strength was significant ($P = 0.002$) difference between groups. WES [pain-free] declined significantly from the baseline during an immediately post-exercise ($p \leq 0.037$) in the hot pack group; however, the WES [pain-free] of the control group decreased significantly from an immediate post-exercise and did not return to the pre-exercise level by 5 days post-exercise ($p \leq 0.048$). The hot pack group significantly demonstrated a lesser deficit in WES [pain-free] than that of the control group on days 1-3 and day 5 post-exercise ($p \leq 0.044$) (Figure 52).

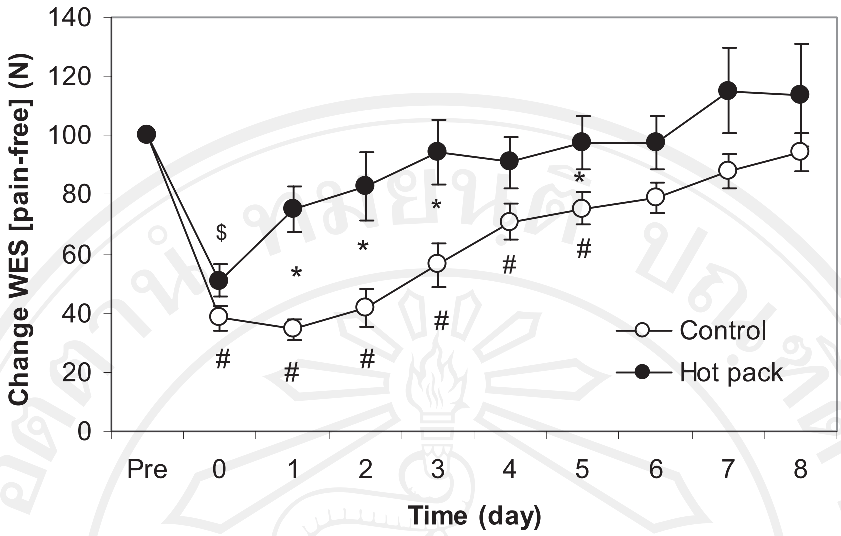


Figure 52 Normalized changes in wrist extensor strength with pain-free (WES pain-free) from the baseline (Pre: 100%), immediately after (0), and 1–8 days following eccentric exercise for the hot pack and control groups. Mean and standard error ($\overline{X}$ ± SEM) are shown for each group. #: significantly different from the baseline in control group (p< 0.05), $: significantly different from the baseline in hot pack group (p< 0.05), *: significantly different between groups (p< 0.05).

4.3.4 A prophylactic effect of sauna on DOMS

Characteristics of the subject in sauna study was showed in the mean age, height, and weight. No significant difference was seen in the mean age, height, and weight between groups. All subjects were able to complete each set of the exercise induction protocol. No significant differences in mean maximal torque and total work during the eccentric exercise were evident between the control and sauna groups (Table 7).

Table 7 Mean and standard deviation ($\overline{X}$ ± SD) of subject's characteristics (age, height, and weight) and work load during eccentric-exercise induction in control and sauna group.

Characteristics	Control group (N = 14)	Sauna group (N = 14)
Age (years)	21.07 ± 1.59	20.64 ± 1.69
Height (cm)	173.14 ± 5.14	170.07 ± 4.76
Weight (kg)	61.29 ± 9.55	61.93 ± 9.03
Peak Torque (N)	3.25 ± 0.87	4.01 ± 1.30
Total Work (J)	180.03 ± 56.61	175.78 ± 73.09

No significant difference between groups were evident for all data

4.3.4.1 Blood flow and skin temperature before and after sauna application

There was a significant increase in blood flow measurements taken before sauna (14.91 ± 9.18 flux/ min) and after sauna applications (70.15 ± 30.74 flux/min) ($p < 0.001$). The skin temperature was also significantly different between before (31.76 ± 1.30^{o} C) and after application of sauna (33.85 ± 1.40^{o} C) ($p < 0.001$).

4.3.4.2 Baseline measures

No significant ($p \geq 0.113$) differences in the baseline values between groups were observed for CPT, PF, AF and GS. However, the dependent variables PPT, PE, AE and WES were significantly different ($p \leq 0.023$). Therefore, normalized data were used to adjust a variation among individual subjects.

4.3.4.3 Pain intensity

Muscle soreness developed immediately after exercise, peaked 1-2 days post-exercise, and disappeared within a week for both groups. The changes in muscle soreness were not significantly different between control and PNF groups for VAS ($p = 0.978$) (Figure 53) and LS ($p = 0.632$) (Figure 54).

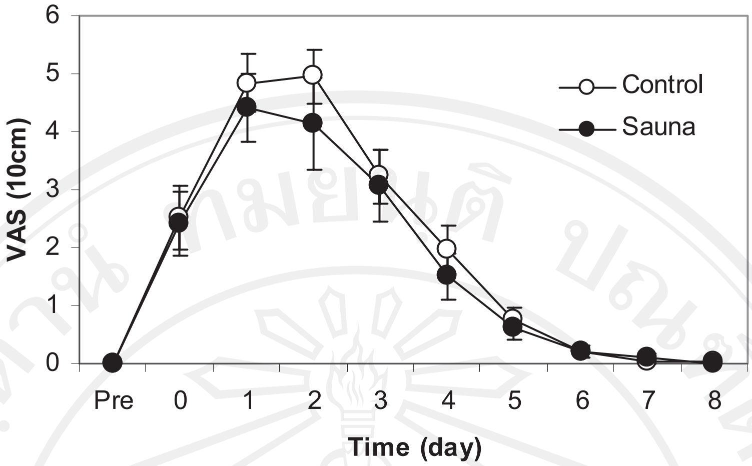


Figure 53 Mean and standard error of mean ($\overline{X} \pm$ SEM) of average pain, visual analogue scale (VAS) from pre-exercise (Pre), immediate after (0), 1–8 days following eccentric exercise for the sauna and control groups.

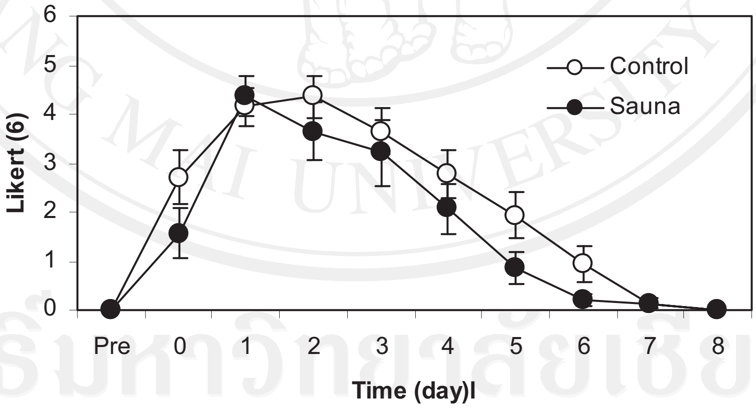


Figure 54 Mean and standard error of mean ($\overline{X} \pm$ SEM) of average pain, Likert's scale (LS) from pre-exercise (Pre), immediate after (0), 1–8 days following eccentric exercise for the sauna and control groups.

4.3.4.4 Pain threshold

No significant (p = 0.198) difference in the changes of thermal pain threshold was evident between groups. The changes in PPT was also not significantly different between control and sauna groups (p = 0.547).

4.3.4.5 Range of motion

Range of motion was assessed in passive and active modes of flexion and extension, In the control group, the passive range of wrist flexion was significantly decreased when comparing the range achieved within the pre-exercise period to the first 5 days of post-exercise ($p \leq 0.011$). In the sauna group, ROM-PF was only significantly decreased when comparing the range achieved during the pre-exercise period to day 2 post-exercise (p = 0.043). The sauna group demonstrated a significantly lower deficit in ROM-PF than the control group on days 1-7 post-exercise ($p \leq 0.029$) (Figure 55). It was also found that the passive range of wrist extension was significantly decreased when comparing the range at pre-exercise to immediately post-exercise and days 1-3 post-exercise ($P \leq .01$) in the control group. In the sauna group, ROM-PE was no significant difference when comparing the range at pre-exercise. The sauna group significantly demonstrated a lesser deficit in ROM-PE than the control group on days 1-2 post-exercise ($P \leq .012$) (Figure 56). However, there was not significantly different between control and sauna groups in active range of wrist flexion (p = 0.087) and extension (p = 0.191).

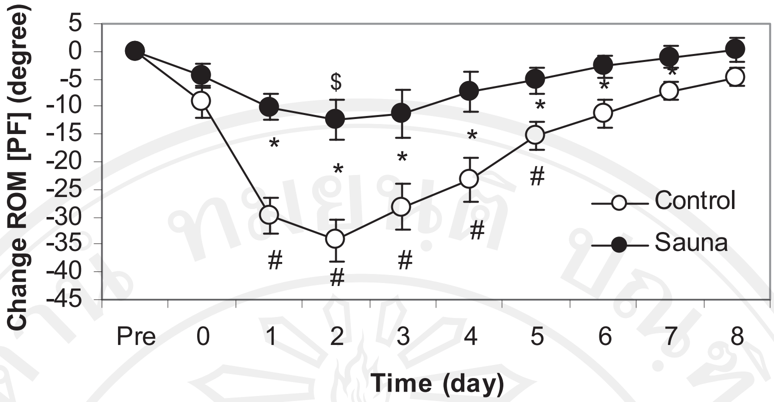


Figure 55 Relative changes in range of motion in passive flexion (PF) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the sauna and control groups. Mean and standard error of mean ($\overline{X} \pm$ SEM) are shown for each group. #: significantly different from the baseline in control group ($p < 0.05$), $: significantly different from the baseline in sauna group ($p < 0.05$), *: significantly different between groups ($p < 0.05$).

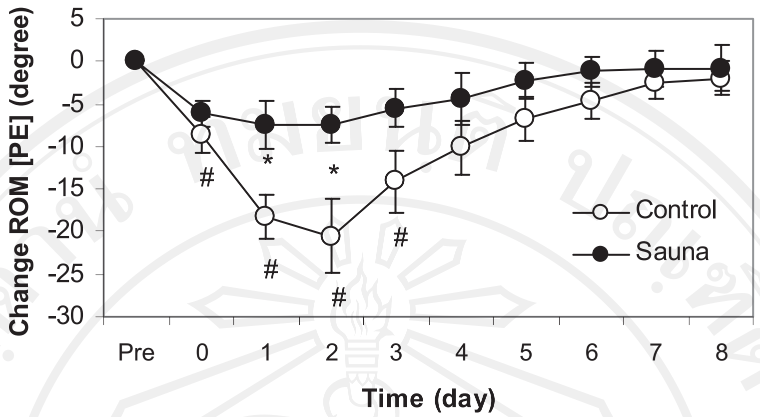


Figure 56 Relative changes in range of motion in passive extension (PE) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the sauna and control groups. Mean and standard error of mean ($\overline{X}$ ± SEM) are shown for each group. #: significantly different from the baseline in control group (p< 0.05), *: significantly different between groups (p< 0.05).

4.3.4.6 Muscle strength

Muscle strength was assessed in grip and wrist extension strengths. They were evaluated with pain-free and maximal strengths. Pain-free grip strength was significantly decreased when comparing the strength at pre-exercise to immediately post-exercise, days 1–3 post-exercise ($p \leq 0.002$) in the control group. In the sauna group, GS [pain-free] was significantly decreased when comparing the range at pre-exercise to immediately post-exercise and day 1 post-exercise ($p \leq 0.004$). The sauna group demonstrated a significantly lesser deficit in GS [pain-free] than the control group in the immediate post-exercise period and on days 1-2 post-exercise ($p \leq$ 0.038). (Figure 57). Pain-free wrist extensor strength was significantly decreased when comparing the strength at pre-exercise to immediately post-exercise, days 1–5 post-exercise ($p \leq 0.048$) in control group. In the sauna group, WES [pain-free] was significantly decreased only when comparing the range at pre-exercise to immediately post-exercise ($p = 0.002$). The sauna group significantly demonstrated a lesser deficit in WES [pain-free] than that of the control group in the immediate post-exercise period and on days 1-3 post-exercise ($p \leq 0.018$) (Figure 58). However, there was not significantly different between control and sauna groups in maximal grip ($p = 0.337$) and wrist extension strengths ($p = 0.661$).

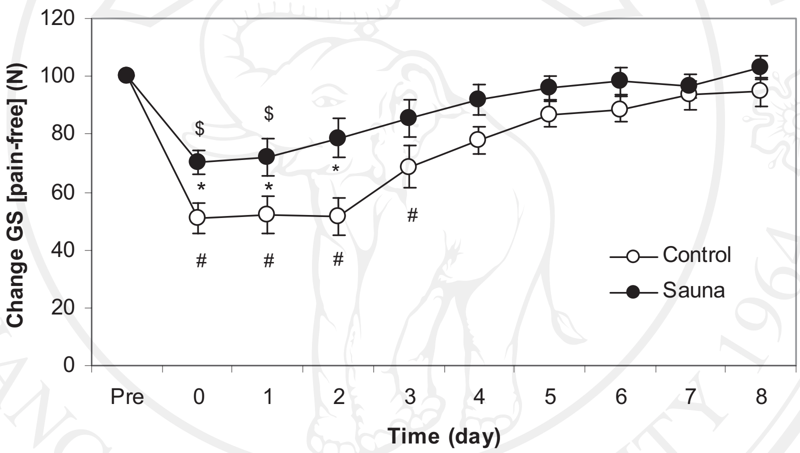


Figure 57 Normalized changes in grip strength (GS) with pain-free from the baseline (Pre: 100%), immediately after (0), and 1–8 days following eccentric exercise for the sauna and control groups. Mean and standard error ($\overline{X} \pm$ SEM) are shown for each group. #: significantly different from the baseline in control group ($p < 0.05$), $: significantly different from the baseline in sauna group ($p < 0.05$), *: significantly different between groups ($p < 0.05$).

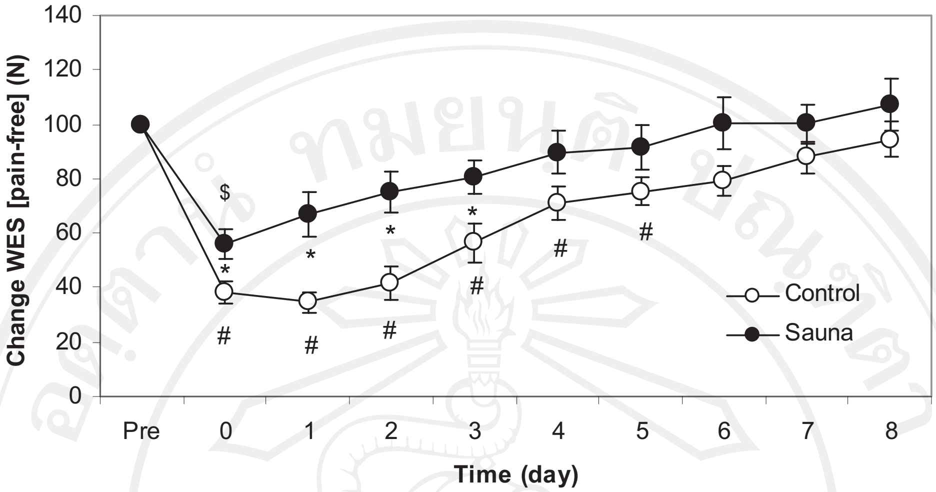


Figure 58 Normalized changes in wrist extensor strength (WES) with pain-free from the baseline (Pre: 100%), immediately after (0), and 1–8 days following eccentric exercise for the sauna and control groups. Mean and standard error ($\overline{X}$ ± SEM) are shown for each group. #: significantly different from the baseline in control group (p< 0.05), $: significantly different from the baseline in sauna group (p< 0.05), *: significantly different between groups (p< 0.05).

4.3.5 Effectiveness between PNF-stretching, massage, hot pack and sauna on DOMS

Comparing the data of 4 interventions including PNF, massage, hot pack and sauna, there was not significantly difference in the outcome measures of VAS; $p \geq 0.400$, LS; $p \geq 0.170$, CPTM; $p \geq 0.237$, PPT; $p \geq 0.166$, ROM-PE; $p \geq 0.129$, ROM-AE; $p \geq 0.170$, GSmax; $p \geq 0.200$, WESmax; $p \geq 0.058$ and WES pain-free; $p \geq 0.108$ among these preventative interventions. Only the outcome measures of ROM-PF, ROM-AF and GS pain-free were found to be significant difference in some of these preventative applications.

ROM-PF was significantly different between the massage and sauna group on day 1 ($p = 0.009$). The ROM-PF was less deficit under the sauna group in comparison to the massage group (Figure 59). ROM-AF was also significant difference between the PNF and hot pack group on day 8 ($p = 0.044$). The ROM-AF was less deficit under the hot pack group in comparison to the PNF group (Figure 60).

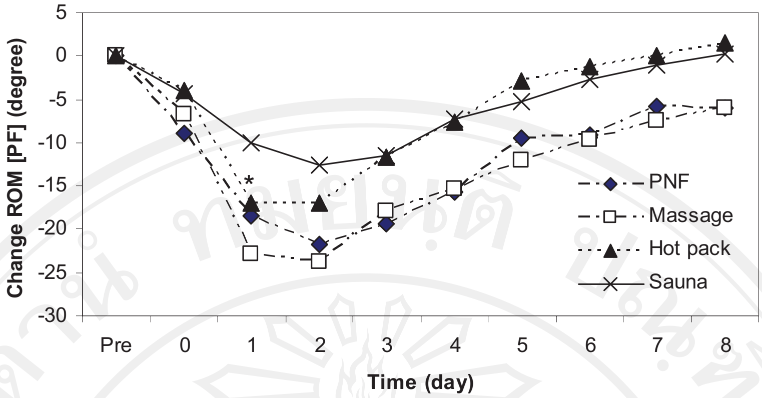


Figure 59 Relative changes in range of motion in passive flexion (PF) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the interventions. Mean ($\overline{X}$) are shown for each intervention. *: significantly different between massage and sauna groups (p< 0.05).

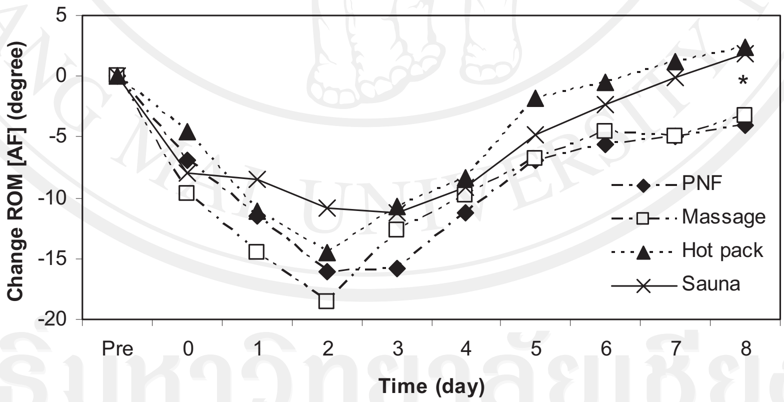


Figure 60 Relative changes in range of motion in active flexion (AF) from baseline (Pre) immediately after (0), and 1–8 days following eccentric exercise for the interventions. Mean ($\overline{X}$) are shown for each intervention. *: significantly different between PNF and hot pack groups (p< 0.05).

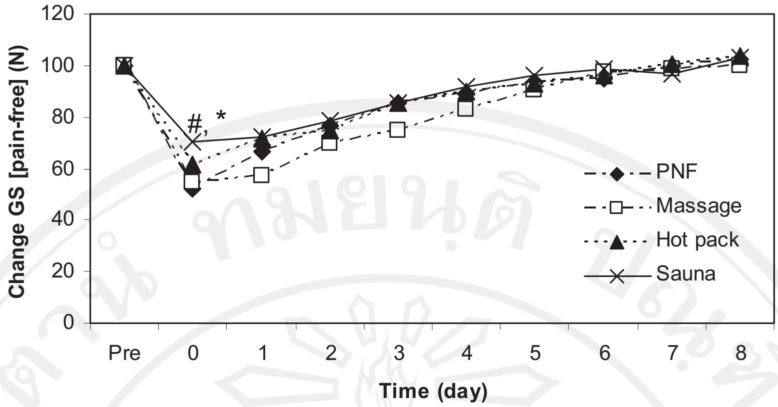


Figure 61 Normalized changes in grip strength (GS) with pain-free from the baseline (Pre: 100%), immediately after (0), and 1–8 days following eccentric exercise for the interventions. Mean ($\overline{X}$) are shown for each intervention. #: significantly different between PNF and sauna group (p = 0.007), *: significantly different between massage and sauna groups (p = 0.027).

In addition, GS pain-free was significant difference between the PNF and sauna group (p = 0.007) at immediately post-exercise. The GS pain-free was less deficit under the sauna group in comparison to the PNF group. GS pain-free was also significantly different between the massage and sauna group (p = 0.027) at immediately post-exercise. The GS pain-free was less deficit under the sauna group in comparison to the massage group (Figure 61).