Recovery From Repeated On-Court Tennis Sessions: Combining Cold-Water Immersion, Compression, and Sleep Interventions

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Purpose: To investigate the effects of combining cold-water immersion (CWI), full-body compression garments (CG), and sleep-hygiene recommendations on physical, physiological, and perceptual recovery after 2-a-day on-court training and match-play sessions. Methods: In a crossover design, 8 highly trained tennis players completed 2 sessions of on-court tennis-drill training and match play, followed by a recovery or control condition. Recovery interventions included a mixture of 15 min CWI, 3 h of wearing full-body CG, and following sleep-hygiene recommendations that night, while the control condition involved postsession stretching and no regulation of sleeping patterns. Technical performance (stroke and error rates), physical performance (accelerometry, countermovement jump [CMJ]), physiological (heart rate, blood lactate), and perceptual (mood, exertion, and soreness) measures were recorded from each on-court session, along with sleep quantity each night. Results: While stroke and error rates did not differ in the drill session ($P > .05$, $d < 0.20$), large effects were evident for increased time in play and stroke rate in match play after the recovery interventions ($P > .05$, $d > 0.90$). Although accelerometry values did not differ between conditions ($P > .05$, $d < 0.20$), CMJ tended to be improved before match play with recovery ($P > .05$, $d = 0.90$). Furthermore, CWI and CG resulted in faster postsession reductions in heart rate and lactate and reduced perceived soreness ($P > .05$, $d > 1.00$). In addition, sleep-hygiene recommendations increased sleep quantity ($P > .05$, $d > 2.00$) and maintained lower perceived soreness and fatigue ($P < .05$, $d > 2.00$). Conclusions: Mixed-method recovery interventions (CWI and CG) used after tennis sessions increased ensuing time in play and lower-body power and reduced perceived soreness. Furthermore, sleep-hygiene recommendations helped reduce perceived soreness.

Keywords: performance, fatigue, court sports, team sports

On-court tennis training and match play involve prolonged, physically demanding activity profiles, resulting in substantial elevation of physiological and perceptual strain and reduced contractile function. Moreover, professional tennis involves year-round scheduling of tournaments, requiring a continued balance of competition to gain and defend ranking points while also ensuring sufficient training for technical- and physical-capacity improvement. To ensure appropriate portioning of time to these demands, players are accustomed to performing multiple sessions a day, generally with a technical, match-play, or physical focus. Accordingly, the need for recovery for ensuing training or competition demands is important for professional players. Interventions such as cold-water immersion (CWI) and compression garments (CG) to assist recovery are popular and supported through research in other sports, while the role of sleep to assist athlete recovery remains an integral but rarely researched area. In a similar vein, the effect of combining these recovery techniques into a mixed-method protocol and application of such a protocol to repeated tennis sessions have not been reported.

CWI and CGs are common recovery tools, often owing to their availability at many competitions (CWI) and portability (CG) during regular travel, while the role of sleep to assist athlete recovery remains an integral but rarely researched area. Despite some conjecture, CWI-induced temperature- or pressure-mediated effects can reduce thermoregulatory and cardiovascular load and muscle-damage markers and improve singular and repeated maximal efforts, which may be of relevance to the frequent training required in competitive tennis. CGs, in turn, are suggested to promote reduced metabolic waste products, increase venous return, and reduce inflammation.
However, evidence for improved recovery of physiological or performance variables after the use of full- or lower-body compression therapy is limited, although improved recovery of lower-body power and perceived soreness has been reported in other sports.

Despite the popularity of the aforementioned interventions, a common issue for recovery from training or competition relates to suboptimal sleeping patterns noted in athletic populations. Sleep is reported to be integral to the metabolic, cognitive, and physiological regenerative processes fundamental to recovery. Indeed, the absence of sleep is reported to blunt muscle glycogen synthesis, elevate thermoregulatory and cardiovascular demands, and slow cognitive and physical performance. Sleep-extension protocols inclusive of sleep-hygiene recommendations improve sleep quantity over time and are reported to improve sports performance, yet no studies report whether such sleep-hygiene recommendations can improve ensuing postexercise recovery in athletes. Furthermore, currently there is no research on the effects of mixed-method recovery interventions, as are anecdotally reported to be used in tennis. Accordingly, the application of mixed-method recovery interventions (CWI, CG, and sleep-hygiene recommendations) may be of relevance to professional tennis, wherein multiple on-court sessions are demanded on a daily basis. Therefore, the aim of this study was to investigate the effects of combining CWI, CG, and sleep-hygiene recommendations on physical, physiological, and perceptual recovery after 2-a-day on-court training and match-play sessions.

**Methods**

**Subjects**

Eight trained, professional male tennis players volunteered to participate. Participant characteristics included mean ± SD age 20.9 ± 3.6 years, body mass 77.6 ± 9.3 kg, and height 183.5 ± 10.2 cm. Of the players, 4 had international rankings in the top 250, while the other 4 were in the process of obtaining an international ranking. All players competed in 25 to 30 tournaments per year, routinely performing 2 or 3 training sessions per day during training phases. All experimentation was approved by the university ethics in human research committee, with written and verbal informed consent provided by the participants after explanation of all procedures.

**Design**

After familiarization with all procedures, participants were matched for age, mass, ranking, and perceived skill level to form pairs for the ensuing tennis sessions. In pairs, participants completed 2 conditions in a randomized, crossover design of on-court tennis training and match play. All participants were awake at 6 AM each morning for a standardized testing start time (8 AM), at which each pair performed a 90-minute on-court session of controlled tennis drills led by a trained coach. After a 3-hour recovery period (at 2 PM), participants then performed a 90-minute match-play session against the same opponents. All procedures in both conditions were standardized and separated by at least 24 hours recovery. Conditions consisted of a control condition (15 min of passive stretching) or a mixed-method recovery condition (consisting of CWI, CG, and sleep-hygiene recommendations). Measures of technical performance (shot volumes and error rates), physical performance (accelerometry), physiological responses (heart rate [HR], blood lactate), sleep quality and quantity, and perceptual responses (mood, perceived exertion, and soreness) were recorded during or after each on-court session. Furthermore, countermovement-jump (CMJ) height for lower-body power, nude mass, and urine specific gravity for hydration status were measured before and after both sessions each day.

Participants abstained from alcohol and intense exercise for 24 hours before and caffeine 3 hours before each session. All fluid, food, and physical activity were standardized before and after each testing session by participants noting consumption and activity in provided diaries and replicating for the ensuing crossover session. Participants were accommodated in hotel rooms each night to standardize sleeping arrangements and were provided access to the same food services at the hotel to standardize nutritional intake of carbohydrate before and after each session at 4 g/kg body mass. Environmental conditions for sessions were 13°C ± 3°C and 40 ± 10% relative humidity.

**Methodology**

Testing was undertaken from 8 to 10 AM and 2 to 4 PM each day, as these times represent common training periods for professional players. Each respective on-court session involved 90 minutes of coach-led drills (including a 30-min warm-up) and 90 minutes of competitive match play. On-court sessions were conducted on the same Plexi-cushion hard-court surface and led by the same coaches, who conferred before each session to standardize ball feed and timing of drills. After a standardized warm-up, players performed 60 minutes of structured technical training consisting of tennis-specific drills (Figure 1) that are often prescribed in technical training of professional players. After a 3-hour recovery period, participants then performed a competitive 90-minute match-play session against the same opponent. Match-play sessions were observed by coaches and scored as per the rules of professional tennis, with participants instructed to replicate match intensities. Furthermore, each drill and match-play session was filmed and later analyzed for notation of shot volume, error rates, and shot-to-rest ratios.

After both on-court sessions, participants performed the recovery or control condition. The recovery intervention consisted of 15-minute whole-body CWI to the suprasternal notch in a seated position in a plunge pool (Ice Bath, White Gold Fitness, Bedford, UK) of ice water at 11°C ± 2°C. CWI was immediately followed by wearing full-body (long-sleeve top and full-length lower-body) CGs (2XU, Melbourne, Australia) that were
individually fit to participants based on height and body mass. CGs were worn between the drill and match-play sessions (for 3.0 ± 0.5 h) and for 4 hours after match play. That night, the sleep-hygiene recommendations involved participants retiring to their provided accommodation and creating a low-light, cool environment at 9 PM. Specifically, participants ensured that all electronic stimulants such as television, mobile phones, and computers were limited or avoided and excessive light was minimized during the ensuing 30 minutes until 9:30, by which time they had retired to bed in a room at 19°C ± 2°C and a light luminescence of 3 to 8 lux (Lux Light Meter, Digitech, Sydney, Australia). Furthermore, participants provided their own sleep eye masks to reduce environmental light during sleep while ensuring comfort and familiarity. Conversely, in the control condition players stretched for 15 minutes after each on-court session, were not provided with CWI or compression, and were allowed to self-regulate exposure to electronic equipment, prebed light (60 ± 12 lux), and sleeping patterns. The aforementioned sleep-hygiene recommendations were based on evidence that elite athletes required to wake early for training often incur suboptimal volume and quality of sleep and that exposure to excessive light and electronic stimuli can retard sleep quality. All sleeping arrangements for both conditions were visually observed by the research team to confirm compliance.

Before each on-court session, players performed a standardized warm-up consisting of the 5’-5’ test to determine HR recovery. The test was performed on a Plexi-cushion hard court in a 20-m shuttle-run fashion at a constant intensity delivered by audio prompts. The reminder of the warm-up consisted of 10 minutes of dynamic footwork drills and 5 minutes of hitting. All drill and match-play sessions were filmed by a digital video camera (DSR-PDX10P, Sony, Japan) located 10 m above and 6 m behind each baseline. Footage was downloaded and viewed later to note for total stroke count including number of forehands, backhands, volleys, serves, forced and unforced errors, error ratios, and rally and rest lengths. Coding was performed using customized software (The Tennis Analyst, V4.05.284, Fair Play, Australia) by a trained analyst with a coefficient of variation <2%. Each player was fitted with a 10-Hz GPS unit (v 2.0, MinimaxX, Catapult, Canberra, Australia) worn in a customized harness between the scapulae to measure 100-Hz triaxial accelerometry of each on-court session. Accelerometry measures (player load) have been reported in other sports as a valid and reliable measure of external load and are expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the 3 vectors (x-, y-, and z-axes). Data were downloaded postsession to calculate player load (Logan Sprint v 5.0, Catapult, Canberra, Australia).

Figure 1 — Movement and stroke patterns of (a) box, (b) bow-tie, and (c) suicide drills.
Before and after each session, nude body mass was recorded (MS3200 Electronic Scales, Charder Electronics, Taichung Hesin, Taiwan) and a midstream urine sample was collected to measure urine specific gravity (Pocket Refractometer, Atago, Japan) to describe hydration status. Furthermore, a 10-μL sample of capillary blood was obtained from an earlobe to measure lactate before and after each on-court session and again after the 15-minute postsession CWI recovery intervention (Lactate Plus, Waltham MA, USA). HR was continuously recorded (Suunto Memory Belts, Suunto Oy, Vantaa, Finland) at 5-second intervals for the entirety of each session (including 5'-5' warm-up and after the 15-min intervention) and downloaded to calculate mean HR for each session (Suunto Training Manager, Suunto Oy, Vantaa, Finland). After the warm-up and immediately after each on-court session, participants completed a repeated CMJ test to determine mean height from 5 repeated unweighted jumps (Jump Mat, Axon, Portugal). After each session, players provided a rating of perceived exertion (Borg CR-10), while perceived muscle and joint soreness (1–10 Likert scale) were provided before and after each session, after the recovery intervention, at 8 PM each night, and then again the following morning (8 AM). The Brunel Mood Scale, consisting of 4 moods with a 5-point rating scale to assess levels of fatigue and vigor, was used before each session, at 8 PM each night, and then again the following morning (8 AM). Finally, players wore an actimetry watch (Rediband, Fatigue Science, HI, USA) to record sleep duration (time in bed, asleep) and quality (efficiency and latency) for the 1 day before testing (baseline) and for all days during the study.

### Statistical Analysis

A repeated-measures 2-way ANOVA (condition × time) was performed to determine differences (P < .05) in technical, physiological, and perceptual responses between recovery interventions. Tukey post hoc t tests were conducted to locate differences where main effects were evident. Effect-size analyses (Cohen d) were used to determine the magnitude of effect of the recovery protocol (<0.20 trivial, 0.20–0.39 small, 0.40–0.89 moderate, >0.90 large).

### Results

As presented in Table 1, there were no significant differences and trivial effect sizes (P > .05, d < 0.10) for total stroke, respective shot, or error counts between conditions for the drill session. However, a moderate effect for increased total stroke count was evident during match play in the recovery condition (P > .05, d = 0.73), despite no difference and trivial to small effects for error rates between conditions (P > .05, d < 0.30). Large effects for an increase in both time in play and shots per minute were evident during match play after the recovery intervention (P > .05, d > 0.90), while a large effect for an increased rest time (ie, time not in play) was evident in the control condition (P > .05, d = 0.81). In contrast, player-load accelerometer values did not significantly differ and showed trivial effect sizes between conditions for drill and match-play sessions (P > .05, d < 0.20; Table 1). CMJ height was not significantly different and exhibited trivial effects between conditions before and after the drill session (P > .05, d < 0.30), although it tended to be higher before match play in the recovery condition (P > .05, d = 0.90; Table 2).

Urine specific gravity was not significantly different between conditions before drill (1.021 ± 0.006 vs 1.023 ± 0.006 AU) or match-play (1.019 ± 0.008 vs 1.015 ± 0.010 AU for recovery and control; P > .05, d < 0.20) sessions, while the change in body mass over drill (−1.60 ± 0.60 vs −1.74 ± 0.65 kg) and match-play (−1.35 ± 0.53 vs −1.56 ± 0.71 kg for recovery and control) sessions also was not different between conditions (P > .05, d < 0.30). The HR recovery after the 5'-5' test before each session did not differ and exhibited trivial effect sizes between conditions (P > .05, d < 0.20; Table 2). Similarly, mean HR during drill (163 ± 12 v 161 ± 8 beats/min) or match-play (131 ± 16 vs 134 ± 16 beats/min for recovery and control, respectively) sessions did not differ between conditions (P > .05, d < 0.30). However, HR was reduced in the recovery condition after the implementation of CWI after both on-court sessions (P < .05, d > 3.00; Table 2). Blood lactate concentration did not differ between conditions before or after either session (P > .05, d < 0.30; Table 2). While the postsession reduction of lactate after the CWI intervention tended to be larger after CWI in the drill session (P > .05, d = 0.80), no differences were evident between conditions after match play (P > .05, d < 0.30).

Rating of perceived exertion did not differ between conditions after the drill (7.3 ± 0.9 vs 7.5 ± 0.9 AU) or match-play sessions (4.3 ± 1.0 vs 4.1 ± 0.9 AU; P > .05, d < 0.20). As presented in Figure 2, perceived muscle and joint soreness did not differ between conditions before the drill session (P > .05, d < 0.30) but were reduced after CWI (P < .05) after the drill session and match-play session that afternoon (P < .05, d > 1.80) and remained lower until the next morning after CG and sleep interventions (P < .05, d > 1.30). No significant differences were present between conditions at any time point for Brunel Mood Scale ratings of fatigue or vigor (P > .05, d = 1.50; Table 2), although large effect sizes were evident for reduced feelings of fatigue the following morning after the sleep-hygiene recommendations.

Sleeping conditions for participants were successfully manipulated to create a low-light environment in the recovery condition (8 ± 5 vs 60 ± 10 lux). Large effects for increased sleep duration in the recovery condition were evident with the implementation of the sleep-hygiene recommendations (P > .05, d = 2.60; Figure 3). The large effects observed for increased sleep duration resulted from both increased minutes in bed and minutes asleep (P > .05, d = 2.41), although no significant differences and small to moderate effects were evident for sleep efficiency in the recovery condition (P > .05, d = 0.79) and sleep latency (time to fall asleep) was not different between conditions (P > .05, d = 0.23).
<table>
<thead>
<tr>
<th>Session</th>
<th>Condition</th>
<th>Duration, min</th>
<th>Stroke count, n</th>
<th>Errors, n</th>
<th>Time in play, min</th>
<th>Shot rate per min</th>
<th>PL, AU</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>FH</td>
<td>BH</td>
<td>Forced</td>
<td>Unforced</td>
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<tr>
<td>Drill 1, “box”</td>
<td>Recovery</td>
<td>9.0 ± 0.6</td>
<td>114 ± 6</td>
<td>84 ± 5</td>
<td>30 ± 2</td>
<td>0 ± 0</td>
<td>23 ± 6</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>9.0 ± 0.7</td>
<td>111 ± 10</td>
<td>82 ± 7</td>
<td>29 ± 3</td>
<td>0 ± 0</td>
<td>28 ± 8</td>
</tr>
<tr>
<td>Drill 2, “bow-tie”</td>
<td>Recovery</td>
<td>9.0 ± 0.9</td>
<td>41 ± 9</td>
<td>57 ± 7</td>
<td>28 ± 12</td>
<td>0 ± 0</td>
<td>16 ± 6</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>9.0 ± 0.7</td>
<td>42 ± 12</td>
<td>57 ± 6</td>
<td>28 ± 9</td>
<td>0 ± 0</td>
<td>15 ± 5</td>
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<td>Drill 3, “suicide”</td>
<td>Recovery</td>
<td>9.0 ± 0.8</td>
<td>100 ± 15</td>
<td>74 ± 13</td>
<td>26 ± 4</td>
<td>0 ± 0</td>
<td>20 ± 6</td>
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<td></td>
<td>Control</td>
<td>9.0 ± 0.9</td>
<td>98 ± 12</td>
<td>72 ± 12</td>
<td>25 ± 4</td>
<td>0 ± 0</td>
<td>20 ± 6</td>
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<td>Drill 4, “cross-court animal”</td>
<td>Recovery</td>
<td>20.0 ± 0.9</td>
<td>250 ± 15</td>
<td>160 ± 15</td>
<td>83 ± 11</td>
<td>3 ± 2</td>
<td>24 ± 6</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>20.0 ± 0.4</td>
<td>260 ± 26</td>
<td>167 ± 17</td>
<td>88 ± 30</td>
<td>2 ± 2</td>
<td>26 ± 8</td>
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<tr>
<td>Drill 5, “recovery”</td>
<td>Recovery</td>
<td>8.0 ± 0.4</td>
<td>83 ± 10</td>
<td>36 ± 7</td>
<td>45 ± 7</td>
<td>2 ± 1</td>
<td>13 ± 5</td>
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<tr>
<td></td>
<td>Control</td>
<td>8.0 ± 0.2</td>
<td>80 ± 8</td>
<td>37 ± 5</td>
<td>41 ± 7</td>
<td>2 ± 1</td>
<td>13 ± 5</td>
</tr>
<tr>
<td>Total</td>
<td>Recovery</td>
<td>56.0 ± 2.3</td>
<td>760 ± 100</td>
<td>479 ± 50</td>
<td>259 ± 58</td>
<td>5 ± 2</td>
<td>105 ± 21</td>
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<tr>
<td></td>
<td>Control</td>
<td>56.0 ± 2.0</td>
<td>790 ± 69</td>
<td>497 ± 20</td>
<td>269 ± 55</td>
<td>4 ± 2</td>
<td>110 ± 18</td>
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<tr>
<td>Match play</td>
<td>Recovery</td>
<td>90.0 ± 0.2</td>
<td>375 ± 65#</td>
<td>130 ± 25</td>
<td>142 ± 29</td>
<td>5 ± 3</td>
<td>33 ± 11</td>
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<tr>
<td></td>
<td>Control</td>
<td>90.0 ± 0.2</td>
<td>334 ± 67</td>
<td>120 ± 30</td>
<td>121 ± 30</td>
<td>5 ± 2</td>
<td>29 ± 10</td>
</tr>
</tbody>
</table>

Abbreviations: FH, forehand; BH, backhand; AU, arbitrary unit.

#Large effect size (d > 0.90) compared with control.
Table 2  Countermovement-Jump (CMJ) Height, Heart-Rate Recovery (HRR), Heart Rate (HR), Blood Lactate (La–) and Brunel Mood Scale Fatigue and Vigor Feelings for Drill and Match-Play (MP) Sessions in Recovery (Rec) and Control (Con) Conditions, Mean ± SD

<table>
<thead>
<tr>
<th></th>
<th>Condition</th>
<th>Predrill</th>
<th>Postdrill</th>
<th>Postrecovery</th>
<th>Pre-MP</th>
<th>Post-MP</th>
<th>Postrecovery</th>
<th>Next morning</th>
</tr>
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<tbody>
<tr>
<td><strong>CMJ, cm</strong></td>
<td>Recovery</td>
<td>40.0 ± 4.0</td>
<td>39.3 ± 3.2</td>
<td>43.8 ± 3.9#</td>
<td>41.0 ± 4.7</td>
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<tr>
<td></td>
<td>Control</td>
<td>39.5 ± 4.0</td>
<td>38.6 ± 6.0</td>
<td>41.6 ± 4.5</td>
<td>39.9 ± 3.8</td>
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<tr>
<td><strong>HRR, beats/min</strong></td>
<td>Recovery</td>
<td>65 ± 7</td>
<td>68 ± 11</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>Control</td>
<td>67 ± 12</td>
<td>68 ± 11</td>
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<tr>
<td><strong>HR, beats/min</strong></td>
<td>Recovery</td>
<td>49 ± 6</td>
<td>163 ± 14</td>
<td>77 ± 8#*</td>
<td>80 ± 10</td>
<td>126 ± 12</td>
<td>70 ± 9#*</td>
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<tr>
<td></td>
<td>Control</td>
<td>49 ± 6</td>
<td>164 ± 9</td>
<td>89 ± 4</td>
<td>82 ± 9</td>
<td>128 ± 17</td>
<td>81 ± 8</td>
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<tr>
<td><strong>La–, mmol/L</strong></td>
<td>Recovery</td>
<td>1.8 ± 0.5</td>
<td>6.5 ± 3.2</td>
<td>2.1 ± 0.7</td>
<td>1.3 ± 0.4</td>
<td>2.5 ± 1.2</td>
<td>1.7 ± 0.4</td>
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<tr>
<td></td>
<td>Control</td>
<td>1.7 ± 0.6</td>
<td>4.7 ± 1.0</td>
<td>2.3 ± 1.4</td>
<td>1.2 ± 0.6</td>
<td>2.1 ± 1.3</td>
<td>1.5 ± 0.6</td>
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<tr>
<td><strong>Fatigue, AU</strong></td>
<td>Recovery</td>
<td>9.0 ± 2.0</td>
<td></td>
<td>10.0 ± 3.2</td>
<td>11.0 ± 2.8</td>
<td>8.8 ± 1.9#</td>
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<tr>
<td></td>
<td>Control</td>
<td>8.5 ± 1.9</td>
<td></td>
<td>9.6 ± 3.5</td>
<td>10.8 ± 3.6</td>
<td>11.4 ± 2.9</td>
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<tr>
<td><strong>Vigor, AU</strong></td>
<td>Recovery</td>
<td>8.4 ± 3.0</td>
<td></td>
<td>8.9 ± 3.4</td>
<td>8.0 ± 4.0</td>
<td>8.4 ± 3.2</td>
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<tr>
<td></td>
<td>Control</td>
<td>8.9 ± 3.2</td>
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<td>8.1 ± 3.3</td>
<td>7.4 ± 3.5</td>
<td>8.0 ± 3.1</td>
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</table>

#Large effect size (d > 0.90) compared with control. *Significant difference (P < .05) compared with control.

Figure 2 — Perceived (a) muscle and (b) joint soreness before and after drill and match-play (MP) sessions, after the recovery period (Rec), at 8:00 the night of and 8:00 next morning for recovery and control conditions, mean ± SD. *Significantly different from control condition (P < .05).
Discussion

This study reports the effects of a mixture of recovery methods (CWI and CG) combined with sleep-hygiene recommendations on recovery from twice-a-day tennis sessions. The on-court sessions used here represent a standardized bout of drills followed by competitive match play—the combination of which would be most likely observed as players approach the commencement of a tournament or in the latter stages of a precompetition training phase. Postsession CWI and CG exhibited large effects for increased CMJ, stroke rates, and time in play for the ensuing competitive match play. Furthermore, postmatch CWI and CG reduced perceived soreness, while the addition of sleep-hygiene recommendations improved sleep quantity and blunted the perception of soreness the next day. Accordingly, the combined use of CWI, CG, and sleep-hygiene recommendations may benefit athlete recovery after twice-a-day on-court tennis sessions.

Technical-stroke outcomes are fundamental to tennis performance, although between-matches comparisons are difficult due to a multitude of factors affecting outcomes. In the current study, initial sessions were coach-led and did not differ in volume, type, or error rates of technical stroke play or in accumulated accelerations between conditions, suggesting similar technical and physical loads. After the use of CWI and CG, large effects for increased total stroke count, shots per minute, and time in play were evident in ensuing match play. Previous research suggests that CWI improves subsequent bouts of cycle ergometry, intermittent-sprint exercise, and skeletal-muscle contractile function due to reductions in physiological load or increased neuromuscular recruitment. The current technical outcomes of increased time in play and stroke rates suggest an increase in match-play-related activities, perhaps akin to the increased work performed in previous research. The notion of recovery interventions’ increasing match-play engagement may seem counterintuitive. However, it is proposed that the improved physical and perceptual state resulted in the elongation of point play as players searched for appropriate opportunities to hit winners or force opponents into error, as well as leading to a reduction in the recovery time between points, culminating in increased match-play engagement. However, similar match-play accelerometry between conditions implies no difference in gross physical movement. Given the lack of validation of whole-body accelerometry measures for tennis movement or technical outcomes, such data may lack sensitivity compared with traditional match notation. Regardless, the current findings suggest that the use...
of mixed-method recovery after on-court sessions may increase ensuing match-play engagement, as evidenced by increased strokes per unit of time.

Given the relevance of lower-body peak power to physical and technical tennis performance, the large effects noted for recovery of CMJ at the commencement of match play are relevant for repeated daily tennis sessions. CMJ was reduced after the drill session in both conditions, although it tended to be increased after the recovery intervention for match play. Previous studies report equivocal findings regarding postexercise recovery of lower-body power with CWI, although improved peak isometric torque, sprint speed, and peak power with CWI have been reported after prolonged intermittent-sprint activity. While most studies report no discernible effect of CG on postexercise recovery of peak power, there is evidence that compression therapy has small positive effects on CMJ performance. Although no further mechanistic insight can be provided in the current study, a large effect indicating improved CMJ recovery was observed after CWI and CG that could benefit players requiring multiple daily sessions.

CWI as a recovery modality is proposed to reduce thermoregulatory load, increase intrathoracic pressure affecting blood volume, and reduce interstitial leakage of markers of cellular damage. Similarly, CGs are proposed to alter distal-to-proximal intramuscular pressure gradients to assist venous return and promote muscle metabolite clearance. The current study observed no effect of recovery interventions on HR or lactate responses to on-court sessions, although reductions in HR and lactate were evident after CWI intervention. Such a finding is common, likely due to the increased hydrostatic pressure attributable to CWI, although the comparison of passive rest during CWI with active stretching during control is acknowledged as a limitation. Regardless, these effects seem transient, as HR recovery, HR, lactate, and urine specific gravity did not differ between conditions before the ensuing afternoon match-play session. Hence, any acute alteration to blood volume from CWI (as inferred by HR changes) was not prolonged by use of CG and is unlikely to relate to the large effects noted in improved CMJ or match-play performance observed in the ensuing afternoon session. Of further note, the cool climatic conditions of the current study are also likely to result in tolerable thermoregulatory loads and hence limit the effectiveness of CWI to improve recovery via reduction of thermoregulatory strain.

Sleep is assumed to be integral to recovery of athletic performance, and while it remains underinvestigated in a sport setting, some evidence suggests that sleep volume and quality are restricted by early training-start times. The current study presents novel data in a sporting context that simple sleep-hygiene recommendations can improve acute sleep quantity in athletes and may additionally help improve perceptual recovery of soreness and mood the following day. Sleep is known to have both physiological and cognitive regenerative properties, and the creation of an environment conducive to sleep provides some evidence that acute postsession sleep quantity can be improved with sleep-hygiene protocols. The current protocol served as a practical recommendation (in athletes) of commonly recommended sleep-hygiene practices. Specifically, to attempt to create a conducive environment to increase sleep by attempting to invoke earlier melatonin onset, reduce core temperature and limit stimuli that would disrupt sleep onset. Although further research is required on sleep-hygiene procedures, ensuring earlier bedtime and a conducive sleep environment can potentially improve perceptual recovery the next day.

Accordingly, improved perceptual recovery after training and competition, while not as objective as performance outcomes, is nonetheless still an important component of athlete recovery. Rating of perceived exertion did not differ between conditions in either session, suggesting limited effect of CWI and CG on internal load. Conversely, although muscle and joint soreness increased after both court sessions, CWI and CG resulted in acute and prolonged reductions in perceived soreness. Individually, the recovery interventions are commonly reported to improve perceptual feelings of soreness, fatigue, and recovery, although whether such findings are intervention-related or placebo-induced remains an often debated topic. Furthermore, inclusion of an effective sleep-hygiene protocol maintained the reduced perception of soreness and fatigue until the following morning. In agreement, recent evidence highlights small but significant associations (r = .20 to .27) between perceived fatigue state and total sleep time. Consequently, while the current study may not add further insight on the mechanisms of the interventions, postexercise CWI and CG, when further supplemented by improved overnight sleep duration, are successful tools to reduce perceived soreness and fatigue after repeated daily on-court sessions.

In conclusion, mixed-method recovery interventions consisting of CWI (15 min at 10°C) and CGs (~3–4 h) used after on-court sessions demonstrated large effects for increased time in play and lower-body power and reduced muscle and joint soreness at ensuing sessions. Furthermore, alongside these interventions, a sleep-hygiene protocol (low light, earlier to bed, 19°C room, sleep with eye masks) helped reduce muscle and joint soreness the next morning after 2-a-day sessions on hard courts. These findings may also be applicable to a range of other athletes required to perform and recover from twice-daily training and competition sessions.

### Practical Applications

- Twice-a-day on-court tennis sessions result in reduced CMJ performance and increased perceptions of fatigue and soreness.
- Mixed-method recovery interventions (CWI, CG, and sleep) can reduce perceived soreness and fatigue, while assisting performance in tennis-specific outcomes of increased shot rate and reduced error rate.
• A sleep-hygiene protocol (low light, cool conditions, and earlier to bed) can improve acute sleep quantity and may relate to improved perceptual recovery.

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