THE SPECIFICITY OF RESISTANCE TRAINING EXERCISES TO SWIMMING PERFORMANCE: A WAVEFORM ANALYSIS APPROACH

Emmet Crowley¹, John Warmenhoven²,³, Andrew J Harrison¹ and Mark Lyons¹

Biomechanics Research Unit, Department of Physical Education & Sport Sciences, University of Limerick, Ireland¹
Exercise & Sport Science, Faculty of Health Sciences, University of Sydney, Sydney, Australia²
Performance People & Teams, Australian Institute of Sport, Canberra, Australia³

The studies aim was to assess the specificity of dry-land resistance training exercises (RT) to front crawl swimming (FC) using electromyography (EMG) waveform analysis. Fourteen male international and national level swimmers were recruited. EMG data were collected during FC and bench press (BP) and pull up (PU) exercises. 3 x 35 m FC bouts and 3 x 5 repetitions for BP and PU, respectively, one at 70 % and two at 100 % of maximal exertion, with 5 minute inactive recovery between trials. Pearson pointwise correlation identified movement pattern relationships between RT and FC waveforms. The results show that FC and BP only found periods that reached the point wise correlation (r ≥ 0.5) and time series (≥ 5%) threshold for the tricep brachii and upper trapezius. This series of analysis may aid in developing a metric for quantifying the specificity of RT to athletic performance.

KEYWORDS: Swimming Performance; Resistance Training; Electromyography; Specificity.

INTRODUCTION: Biomechanical specificity can be defined as the degree of similarity between two exercise modes and involves several components; the range of motion, joint angles, velocity, posture and muscle activity while performing movements (Gamble, 2006). The measurement of specificity of these biomechanical components can inform the practitioner of the specificity of RT to swimming performance. The swimming literature has highlighted the importance of neuromuscular adaptations in the transfer of RT to FC (Crowley et al., 2017).

Previous research by Crowley et al. (2018) has explored the prescription of RT and practices among elite swimming strength and conditioning coaches. The results of this research study found that the BP and PU exercises were the most popular upper body exercises that coaches believed transfer best to improve swimming performance. Furthermore, the findings highlighted the over-reliance by coaches on pseudo-science articles, rather than the use of objective and evidence based sources of information (i.e. journal articles) to inform the prescription of RT for swimmers.

The analysis of complete biomechanical waveforms is becoming more common in biomechanical research as it accounts for the dynamic nature of movement data such as FC and RT. Warmenhoven et al. (2018) reviewed statistical methods that examine sports biomechanical time-series data sets. Functional Data Analysis (FDA) (Ramsay, Hooker, & Graves, 2009) is one such method that has been used across different sports including (but not limited to) race walking, running, Olympic weightlifting, rowing and soccer to compare time-series waveforms (Warmenhoven et al., 2018).

Many studies have highlighted the relationship between RT and FC (Crowley et al., 2018). Limited evidence has linked the muscle activations of RT with the specific muscle activations in FC. The analysis of muscle activations warrant careful consideration when comparing waveforms and determining specificity. This research study used Pearson pointwise correlations to evaluate the similarity of muscle activations between RT and FC. Therefore, the aim of this study was to assess the specificity between BP and PU exercises and FC, respectively.
METHODS: Fourteen male international and national level swimmers (mean age: 18.2 ± 2.55 years; height: 1.84 ± 0.05 m; mass: 76.11 ± 6.52 kg; arm span: 1.89 ± 0.06 m) participated in this study. Participants completed RT at least three times a week and swimming training at least eight times a week. The swimming and RT trials were conducted in a randomised order. Height, arm span and mass were recorded. A standardised warm up (400 m swim; 3 x 100 (50 m drill and 50 m swim); 4 x 50 m (15 m fast, 35 m easy); 100 m easy) was conducted. Participants performed three 35 m swimming trials with a 5 minute inactive recovery period between each trial. Trial 1 was conducted at 70 % of the participant’s perceived maximal exertion, with trials 2 and 3 at maximal exertion. A standardised warm-up (e.g. 2x (5 per leg x lunges, 5 x push-ups and 5 x face pulls)) before each RT session was conducted. Participants performed three trials of 5 repetitions with a 5-minute inactive recovery period between each trial. Trial 1 was conducted at 70 % of the participant’s maximal exertion, with trials two and three at maximal exertion. The Noraxon, Myosystem 1400A (Noraxon, Scottsdale, USA) was used to record EMG signals. EMG sensors were attached following the warm up and before the swimming or the dry-land resistance training trials. The electrode attachment points were located using the Seniam guidelines (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000) for the anterior, posterior and middle deltoid, pectoralis major, latissimus dorsi, bicep brachii, triceps brachii and upper trapezius. Hair at the site of the electrode placement was shaved and the skin cleaned using an alcohol soaked pad. Electrodes (20 mm contact diameter) were placed on the right side of the body on the belly of the muscle and placed 2 cm apart. Two layers of waterproof adhesive tape were applied to each electrode location. It is important to note that the EMG sensors, once attached, were not removed between any of the FC or RT trials. Data were collected using an underwater camera system (240 Hz GoPro, GoPro Inc., San Mateo, California) recording the swimmers in the sagittal plane. Additionally, a 240 Hz Casio (EX-ZR800, Casio Computer Co., Ltd., Tokyo, Japan) camera system was set up on a tripod on the opposite side of the pool. LED trigger synchronized all devices. The EMG signals were sampled at a rate of 1000 Hz. Signals were rectified and filtered using a 4th order Butterworth filter at 12 Hz. The videos were digitised using Kinovea 0.8.15 software. Data processing was conducted between 12.5 m and 22.5 m, as this was the middle section of the 35 m swimming trial. Three stroke cycles were examined within this capture phase. The middle stroke cycle from trial number three was selected. Stroke cycle was determined based on hand entry and re-entry and divided into propulsive and recovery phase. There were four distinct phases of the propulsive phase; catch (0 % - 25 %), pull (26 % - 61 %), push (62 % - 99 %) and exit (100 % - 0 %). The RT event cycle was divided into the eccentric and concentric phase. From the 5 RM, repetition number three from trial number one was used for analysis to avoid cumulative fatigue effects. The x-axis represents the duration of the propulsive phase of FC and the concentric phase of RT (i.e. 100 %). Mean (± SD) and coefficient of variation (CV) are represented using the middle stroke and middle repetition for each participant. Pearson pointwise correlations (Ramsay et al., 2009) were used to analyse the strength of similarity between two time-series descriptively. The pointwise correlation highlighted regions on the curve that showed different strength relationships between FC and RT groups.

RESULTS: The mean (± SD) and CV of each muscle activation revealed considerable variability between participants, see table 1. The CV was largest in the upper trapezius for front crawl swimming, posterior deltoid for bench press and anterior deltoid for pull up. The results of this study demonstrate that with respect to front crawl swimming the latissimus dorsi (64.4%) has the lowest CV and the upper trapezius (92.9%) the highest. Similarly, with respect to the bench press the pectoralis major (42.1%) had the lowest CV and the posterior deltoid (84.9%) the highest CV. In the case of the pull up the posterior deltoid (48.5%) had the lowest CV and the anterior deltoid (94.3%) the highest CV. The Pearson pointwise correlations were identified when r ≥ 0.5, which indicates a strong relationship (Hopkins et al., 2009) and therefore indicates periods of similarity. FC and BP reached this threshold at specific periods across the curve, with the mean (± SD) r – value
reported over these periods: anterior deltoid (23 – 26%, r = 0.61 ± 0.05; 75 – 77%, r = 0.54 ± 0.02; 79 – 80%, r = 0.52 ± 0.01; 95 – 99%, r = 0.65 ± 0.07), bicep brachii (3 – 7%, r = 0.68 ± 0.04; 34 – 35%, r = 0.54 ± 0.02), latissimus dorsi (13 – 15%, r = 0.54 ± 0.02; 18 – 20%, r = 0.52 ± 0.01), middle deltoid (67 – 68%, r = 0.51; 90 – 92%, r = 0.54 ± 0.02), posterior deltoid (46 – 47%, r = 0.5), tricep brachii (4 – 11%, r = 0.62 ± 0.08; 12 – 14%, r = 0.51 ± 0.01; 20 – 21%, r = 0.51) and upper trapezius (8 – 14%, r = 0.59 ± 0.05), latissimus dorsi (47 – 49%, r = 0.57 ± 0.03), middle deltoid (43 – 45%, r = 0.54 ± 0.02) and pectoralis major (96 – 99%, r = 0.53 ± 0.01). However, data that reached ≥ 5% across the time series and r ≥ 0.5 for this period was only observed for FC and BP for the tricep brachii (4 – 11%, r = 0.62 ± 0.08), see figure 1, and upper trapezius (8 – 14%, r = 0.61 ± 0.04; 21 – 35%, r = 0.6 ± 0.05; 59 – 64%, r = 0.61 ± 0.05).

Table 1: The mean, SD and CV of the participants, represented by percentage, for each muscle across the normalised propulsive and concentric phase for front crawl swimming, bench press and pull up.

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th>Anterior Deltoid</th>
<th>Bicep Brachii</th>
<th>Latissimus Dorsi</th>
<th>Middle Deltoid</th>
<th>Pectoralis Major</th>
<th>Posterior Deltoid</th>
<th>Tricep Brachii</th>
<th>Upper Trapezius</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FC Swim</strong></td>
<td><strong>M</strong></td>
<td>22.81</td>
<td>30.51</td>
<td>32.21</td>
<td>30.66</td>
<td>32.65</td>
<td>32.26</td>
<td>33.81</td>
<td>30.68</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>18.80</td>
<td>21.10</td>
<td>20.73</td>
<td>25.59</td>
<td>21.25</td>
<td>22.82</td>
<td>22.13</td>
<td>28.52</td>
<td></td>
</tr>
<tr>
<td><strong>CV</strong></td>
<td>82.42</td>
<td>69.16</td>
<td>64.37</td>
<td>83.48</td>
<td>65.08</td>
<td>70.74</td>
<td>65.46</td>
<td>92.95</td>
<td></td>
</tr>
<tr>
<td><strong>Bench Press</strong></td>
<td><strong>M</strong></td>
<td>41.60</td>
<td>22.21</td>
<td>29.79</td>
<td>42.41</td>
<td>39.81</td>
<td>22.39</td>
<td>24.96</td>
<td></td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>18.68</td>
<td>15.42</td>
<td>19.10</td>
<td>19.07</td>
<td>16.76</td>
<td>20.13</td>
<td>17.61</td>
<td>16.84</td>
<td></td>
</tr>
<tr>
<td><strong>CV</strong></td>
<td>44.90</td>
<td>69.41</td>
<td>64.12</td>
<td>44.95</td>
<td>42.09</td>
<td>89.94</td>
<td>42.21</td>
<td>67.48</td>
<td></td>
</tr>
<tr>
<td><strong>Pull Up</strong></td>
<td><strong>M</strong></td>
<td>24.57</td>
<td>35.23</td>
<td>36.65</td>
<td>30.95</td>
<td>30.95</td>
<td>36.28</td>
<td>35.62</td>
<td>23.40</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>23.15</td>
<td>19.50</td>
<td>19.01</td>
<td>18.56</td>
<td>17.87</td>
<td>17.61</td>
<td>20.21</td>
<td>19.52</td>
<td></td>
</tr>
<tr>
<td><strong>CV</strong></td>
<td>94.25</td>
<td>55.35</td>
<td>51.87</td>
<td>59.97</td>
<td>57.75</td>
<td>48.54</td>
<td>56.74</td>
<td>83.40</td>
<td></td>
</tr>
</tbody>
</table>

FC: Front Crawl; M: Mean; SD: Standard Deviation; CV: Co-efficient of Variation.

Figure 1: Pearson pointwise correlation of the tricep brachii for front crawl swimming and bench press exercise showing similarity during the period of 4 – 11% (r = 0.62 ± 0.08).

**DISCUSSION:** The aims of this study were to investigate the specificity relationship between RT and FC. The Pearson pointwise correlation was applied to investigate the similarity between the movement patterns during the concentric and propulsive phases, respectively. A strong relationship was established when r ≥ 0.5. The results found that when the propulsive phase was compared to the concentric phase of the RT there were few periods of similarity established. Several muscles showed periods of similarity for BP, PU and FC, respectively. The anterior, posterior and middle deltoid, pectoralis major, latissimus dorsi, bicep brachii
showed periods of similarity for FC and BP. Similarly, the anterior deltoid, latissimus dorsi, middle deltoid and pectoralis major for FC and PU. However, BP and FC only found periods that reached the Pearson pointwise correlation and time series threshold for the tricep brachii and upper trapezius. Whilst there is little to no evidence supporting the upper trapezius contributing to the propulsive phase of FC, the tricep brachii has been documented within the literature as a prime mover within FC (Figueiredo et al., 2013). Figueiredo et al. (2013) found the tricep brachii had the highest muscle activation during the push phase. However, the present study highlighted the specificity relationship during the catch phase. Furthermore, the results of this study show large variability within the data set and would suggest that a single general muscle activation pattern (the mean activation pattern of all participants) is not representative of the individual muscle activations. The high variability within this data set requires an alternate approach, due to the mean curve not representing an actual EMG signal. This may explain the inconsistency of similarity established within the data set. Additionally, the investigation of specificity may require the comparison of amplitude and not only movement patterns in isolation. This may be a more thorough approach in establishing a specificity relationship between RT and FC. These findings suggest that there are little relationships found between RT and FC but using Pearson pointwise correlations to identify areas of similarity between movement patterns may be a viable method of analysis.

CONCLUSION: The quantification and evaluation of specificity is challenging. The Pearson pointwise correlations quantify the specificity relationship between two exercise modes. The analysis only identified similarity between FC and BP for the tricep brachii and upper trapezius, with PU and FC showing no areas that met the Pearson pointwise correlation and time series threshold. The large variability within the data set would suggest that individual data analysis techniques would provide further insight into the specificity relationship. Unfortunately, the need for a greater number of repetitions and stroke cycles is challenging, as collecting multiple repetitions at maximal exertion is problematic due to residual fatigue. This series of analysis may aid in developing a metric for quantifying the specificity of RT to athletic performance, but individual analysis techniques are required to counteract the large variability present.

REFERENCES