Countermovement jump to monitor neuromuscular fatigue in endurance athletes

A correlation study between training load and CMJ-variables

Julia Wedman
Abstract

Training load monitoring is crucial to examine fatigue status. The currently available methods show diverse validity, and each come with their limitations. The advantages of CMJ are many and seem to be useful within team sports, although its use on endurance athletes needs more research. Using force plates is agreed to be the best method, but the uncertainty of which variables to use when monitoring fatigue creates difficulties, yet currently, no optimal method is identified. The purpose of this study was to investigate the use of CMJ and its variables on endurance athletes. Ten triathletes participated in the study, performing the CMJ two times a week for five weeks. The training load from each session was quantified using Lucia’s TRIMP. A correlation analysis between total TRIMP three days prior to testing and eight different CMJ-variables were made; jump height-flight time (JH-FT), jump height-impulse (JH-IM), Reactive Strength Index-flight time (RSI-FT), Reactive Strength Index-impulse (RSI-IM), braking duration (B-DUR), braking impulse (B-IM), propulsive duration (P-DUR), propulsive impulse (P-IM). A small positive correlation was found between TRIMP and JH-FT ($r = 0.23$), JH-IM ($r = 0.24$), RSI-FT ($r = 0.13$), and RSI-IM ($r = 0.13$). B-DUR and B-IM had a small negative correlation ($r = -0.10$, $r = -0.11$) while P-DUR and P-IM showed no correlation ($r = < 0.02$). No significance was found in any correlations ($p > 0.05$). Results indicated that JH may provide better information about fatigue compared to other variables. Variables from the braking phase seem more sensitive to training load compared to the propulsive phase. Using flight time seems to provide similar results as impulse which could simplify fatigue monitoring. However, due to limitations of the study the results should be viewed with caution and more research is needed for further conclusions.

Keywords; Jump height, Reactive Strength Index, Flight time, impulse
**Abbreviation**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ</td>
<td>Countermovement jump</td>
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<td>JH</td>
<td>Jump height</td>
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<td>FT</td>
<td>Flight time</td>
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<td>TL</td>
<td>Training load</td>
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<td>GPS</td>
<td>Global positioning system</td>
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<td>TRIMP</td>
<td>Training impulse</td>
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<td>RPE</td>
<td>Rating of perceived exertion</td>
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<tr>
<td>JH-FT</td>
<td>Jump height calculated by flight time</td>
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<td>JH-IM</td>
<td>Jump height calculated by impulse</td>
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<td>RSI-FT</td>
<td>Reactive Strength Index calculated by flight time</td>
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<td>RSI-IM</td>
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<tr>
<td>B-DUR</td>
<td>Braking duration</td>
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<td>Braking impulse</td>
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<td>P-DUR</td>
<td>Propulsive duration</td>
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<td>P-IM</td>
<td>Propulsive impulse</td>
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<tr>
<td>HR</td>
<td>Heart rate</td>
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<tr>
<td>Z</td>
<td>Zone</td>
</tr>
</tbody>
</table>
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>1</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>2</td>
</tr>
<tr>
<td>Introduction</td>
<td>4</td>
</tr>
<tr>
<td>The importance of training load monitoring</td>
<td>4</td>
</tr>
<tr>
<td>Current methods for monitoring training load</td>
<td>5</td>
</tr>
<tr>
<td>The countermovement jump</td>
<td>5</td>
</tr>
<tr>
<td>Method</td>
<td>8</td>
</tr>
<tr>
<td>Participants</td>
<td>8</td>
</tr>
<tr>
<td>Equipment and methods</td>
<td>8</td>
</tr>
<tr>
<td>Procedure</td>
<td>9</td>
</tr>
<tr>
<td>Statistical analysis</td>
<td>10</td>
</tr>
<tr>
<td>Ethics</td>
<td>10</td>
</tr>
<tr>
<td>Results</td>
<td>11</td>
</tr>
<tr>
<td>Discussion</td>
<td>15</td>
</tr>
<tr>
<td>Methodological reflection</td>
<td>16</td>
</tr>
<tr>
<td>Ethical and societal reflections</td>
<td>19</td>
</tr>
<tr>
<td>Conclusion</td>
<td>21</td>
</tr>
<tr>
<td>References</td>
<td>22</td>
</tr>
<tr>
<td>Attachments</td>
<td>24</td>
</tr>
</tbody>
</table>
Introduction

The importance of training load monitoring

The importance of monitoring training load has been highly emphasized in research over the years. It is essential to monitor the load to determine adaptations to training, minimize the risk of non-functional overreaching, injury and illness (1-5). Training load can be divided into external or internal load. Internal load is the relative physiological and psychological stress imposed on the body during training and competition. On the other hand, the external load is the athlete’s objective work and is measured independently of the internal responses (3). Halson (2) defines fatigue as a “failure to maintain the required or expected force”. Both Alba-Jiménez et al. (6) and Pau-Yen Wu et al. (4) address two different kinds of fatigue, metabolic and neuromuscular. The fatigue of metabolic origin has a short-term effect on the capacity to generate force due to the exceeded rate of ATP replacement caused by exercise. This type of fatigue can last up to three hours. Neuromuscular fatigue has, on the other hand, a prolonged origin, and results in a decrease of the ability to produce voluntary force due to exercise, either in terms of repeated or sustained muscular contractions. The recovery time of neuromuscular function seems unclear, with research showing results ranging from 24-48 hours up to 4 days (4, 6).

Halson (2) highlights the importance of monitoring training load in order to understand fatigue in athletes. Adjustments in training load are used to ensure that fatigue is appropriately added to optimize adaptations and performance hence the importance of finding methods to accurately monitor load. Furthermore, Halson also points out the challenges that come with fatigue monitoring. In team sports, skill performance, cognitive load and fatigue that influence decision making needs to be considered. However, when it comes to individual endurance sports, fatigue is at a higher rate as a result of high training load which makes accurate monitoring highly important in order to determine fatigue status. Moreover, Mujika et al. (5) implies that it is not possible to determine the effects of training and its adaptations on performance without an accurate quantification of training load. Additionally, the importance of monitoring training load for the purpose to reduce the risk of injury is strongly highlighted by Gabbet (7). According to Gabbet it is not high training load per se that leads to injury but when the load is increasing to an excessive dose too rapidly. Matos et al. (8) have shown similar results in trail runners and therefore recommends load monitoring to avoid large spikes in the workload to reduce the injury risk. Furthermore, training load monitoring is not only beneficial for scientific understanding of changes in performance and fatigue but also when it comes to communication. On one hand it
can enhance the athletes feeling of involvement and ownership in the training program. On the other hand, it will also support the communication within the staff when the support staff and coach staff are forced to communicate around the training load (2, 5).

**Current methods for monitoring training load and fatigue**

Taylor et al. (1) reviews the current trends in fatigue monitoring in high performance sports. The study shows through a survey among sport coaches that self-reported questionnaires, performance tests (e.g., sprint and vertical jump) and performance tracking (e.g., GPS-data) were the most commonly used methods for monitoring training load and fatigue. However, Self-reported questionnaires rely on memory and a subjective evaluation of perceived effort while GPS-system lack accuracy in some sports events where the quantification of specific load cannot be made (jumps, tackles, kicks etc.) which makes their use somewhat questionable (2, 3, 6). Within endurance sports, Mujika et al. (5) mentions numerous methods available to quantification of training load; Oxygen consumption, lactate and heart rate measurements such as HR-RPE-ratio, TRIMP, Lactate-RPE-ratio, HR-recovery, HR-variability, HR-zone score etc. Physiological measurements like these may provide valid and reliable information about training intensity but the use for athletes without technical and financial resources may be limited (5). Biochemical markers, such as testosterone, cortisol and creatine-kinase which appear to be efficient methods but the fact that they are impractical, time-consuming, expensive and require expertise to collect and analyze makes them use less common (1, 2, 5). Currently there is no single method identified to accurately measure an athlete’s fatigue status (1, 2, 5, 7).

**The countermovement jump**

Countermovement jump is a measure of neuromuscular capacity and reactive strength and is used to determine training adaptations, readiness and return to play after injury. The test is not only a practical, simple, and time-efficient but above all, non-fatiguing. Additionally, with its high practicality and low physiological load it allows repeated assessments of multiple individuals during a short period of time (1, 6-8). The test is well studied and shown high validity and reliability to fatigue within team sports such as basketball, rugby and football (6). Alba-Jiménez et al. (6) claim that the CMJ is the golden standard for monitoring neuromuscular fatigue in high performance sports. However, results regarding the effectiveness of the countermovement jump as a measure of neuromuscular fatigue are mixed (9). Claudino et al. (9) suggest that an underlying factor could be the fact that different
measurements variables available when measuring the CMJ have different sensitivity to an athlete's neuromuscular function. hence they recommend future research to determine the use of different variables. Along the same lines, Taylor et al. (1) remarks that there is limited consensus on what the optimal approach for accurately measuring fatigue status is, given the broad range of protocols and variables currently utilized. Thus, they suggest that more research is needed on development and validation of methods that through testing of maximal neuromuscular performance can monitor fatigue and recovery.

Testing of the CMJ can be done with several different apparatus with force plates being the gold standard and is frequently used for research purposes. However, due to its lack of portability and high cost, other methods (mat systems, phone apps) are instead utilized by coaches in field testing (10). According to McMahon et al. (11) the development of affordable and valid force plates is increasing, making the future for its use among strength and conditioning coaches bright. In terms of variables to use for assessing fatigue through the CMJ there is a wide range available, and research are not providing a clear picture. Taylor et al. (1) illustrates that jump height (JH) calculated by flight time is the most commonly used metric, but its usefulness has become somewhat questionable. Some research proves that JH by flight time results in measurements errors and inconsistent results and should not be replaced by JH calculated by impulse, which now is considered the golden standard (12, 13). Average JH is shown to be more sensitive to fatigue compared to maximal JH but recently researchers have started to investigate the use of other metrics to examine fatigue status. Force plates allow us to gather a more comprehensive insight of the neuromuscular function by producing metrics on jump strategy (e.g duration, time to take-off) and not solely outcome metrics (e.g. JH and RSI) (9). Ellis et al. (14) are mentioning that those kinds of measurements are more sensitive than JH to change during different phases of training load in microcycles and Bishop et al. (10) show that force time-variables are more likely to change when testing CMJ after intense exercise periods, return to play after injury and long term athlete development. Claudino et al. (9) is mentioning that variables such as peak velocity, peak power, mean power, peak force, power and mean impulse are sensitive to tracking supercompensation in training and might therefore be a better suggestion for fatigue monitoring than JH. Bishop et al. (10) have also shown reactive strength index (RSI) to be highly sensitive to changes in training load. Gathercole (15) claims that less commonly used metrics such as concentric duration and total duration may detect important fatigue-related changes that otherwise would be missed. The different phases of the CMJ may be affected differently when fatigued due to physiological responses in the body. Ellis et al. (14)
show that the propulsive phase remains relatively unchanged while the force-time components from the braking phase were more likely to change during different days in a microcycle. Taylor et al. (1) and Claudino et al. (9) also state that the braking phase is sensitive to fatigue induced during high training load periods. However, Pau-Yen Wu et al. (4) showed that metrics from the propulsive phase (e.g. relative and time to peak force, concentric duration) to be a good predictor for both metabolic and neuromuscular fatigue making the consensus of the use of variables from different phases unclear.

In summary training load monitoring is highly important to examine fatigue in order to optimize performance and minimize risk of injury and overreaching. Currently, there are numerous methods available for load monitoring, however many of the methods show diverse validity and are also expensive, time-consuming, and/or require expertise to collect and analyze making the load monitoring challenging. The CMJ is commonly used team sports and has many advantages with it being effective, simple, relatively inexpensive, and non-fatiguing. Research is however dominated by team sports making its use in endurance environments unclear. Force plates can give a deep picture of an athlete’s neuromuscular status but the uncertainty of which variables to use for fatigue monitoring creates its difficulties. Research agrees that no single optimal method has been identified for training load-monitoring and more research towards the CMJ and its variables is warranted.

The primary aim of this study is to determine whether the CMJ can be used as a measurement of training load to effectively monitor fatigue status in endurance athletes. The secondary purpose is to investigate CMJ-metrics of different types and their sensitivity to changes in fatigue.

Research statements;

a) How does average jump height calculated by flight time (JH-FT) versus impulse (JH-IM) correlate to training load in endurance athletes?

b) How does Reactive strength index calculated by flight time (RSI-FT) versus impulse (RSI-IM) correlate to training load in endurance athletes?

c) How do the metrics (impulse + duration) from the propulsive phase versus the braking phase of the CMJ correlate with training load in endurance athletes?
Method

Participants
Fifteen triathletes were recruited to the study using convenience sampling. The athletes were training at the facility where the study was conducted. Most of the participants belonged to the same training group and got recruited by their coach whereas a some were approached and recruited directly by the author of this paper. All athletes were actively competing on elite level and had little to no experience with the countermovement jump. Inclusion criteria to participate in the study were limited to endurance athletes on elite level, here defined as actively competing on highest national level. Furthermore, the participants had to be able to perform the CMJ two times a week and collect external training load in terms of minutes in different pace-zones every single training session during the whole project. If assessment of the CMJ were missed the related training load-data were excluded from the analysis. Vice versa, if training load data were missed to be collected, the following CMJ-result was removed. Exclusion criteria for the study itself was if five or more assessments had to be excluded from the analysis. Out of the 15 recruited participants, data from ten athletes were included in the study. Out of the five participants who were excluded from the study, three were removed as they missed more than five assessments. One had to withdraw his participation due to illness and one did not get permission from his coach to participate. The characteristics of the ten participants are shown in table 1.

<table>
<thead>
<tr>
<th>Table 1. Average characteristics-values of the participants before the study</th>
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<tr>
<td>Number (N)</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Men</td>
</tr>
<tr>
<td>Women</td>
</tr>
</tbody>
</table>

*Note: SD = standard deviation.*

Equipment and methods
The countermovement jumps were performed on force-plates (Bertec FP4550-08™, Ohio, USA) and the software used to collect the data from the force-plates was myoRESEARCH® (Noraxon, USA). Bertec force-plates are the gold standard in numerous of studies examining the validity of other equipment for jump assessments (16-21). Lucia’s TRIMP method (22) was utilized to quantify the training load. The Lucia’s TRIMP method is a heart rate (HR) based method and seem to be a reliable and valid method in endurance sports such as cycling where the heart rate is relatively continuous (22, 23). The three heart rate zones (Z) were
customized to each athlete’s ventilatory threshold (VT) based on previously executed gas
analyze assessments. Zone 1 referred to training below the first threshold (VT1), zone 2
between VT1 and the second threshold (VT2) and zone 3 above VT2. To obtain the TRIMP
score, duration (minutes) spent in each zone were multiply with a constant value (1, 2 or 3)
depending on the intensity zone. The total sum from each zone
resulted in the TRIMP-score.

\[ TRIMP = \text{Duration } Z1 \times 1 + \text{Duration } Z2 \times 2 + \text{Duration } Z3 \times 3 \]

The time spent in different heart rate zones were collected by the athletes using their own
heart rate band with corresponding monitoring system. A standardized protocol for the
countermovement was followed to ensure high reliability of the assessments. Furthermore, the
athletes were informed to wear the same shoes at every assessment to reduce the risk of
external factors affecting the result. The following eight CMJ-variables were collected from
the assessments: jump height-flight time (JH-FT), jump height-impulse (JH-IM), Reactive
Strength Index-flight time (RSI-FT), Reactive Strength Index-impulse (RSI-IM), braking
duration (B-DUR), braking impulse (B-IM), propulsive duration (P-DUR), propulsive
impulse (P-IM). Jump height is the height of the jump in centimeters calculated by either
flight time or by impulse. RSI is calculated by the taking the flight time divided by the time
between initiation of movement and take-off (24). Impulse is defined as the integral of a force
during the time interval the force is applied (25). The braking phase is the eccentric part of the
jump and starts with negative center of mass velocity and stops in the deepest point in the
countermovement where zero velocity is achieved. The propulsive phase is the concentric part
and starts right after the braking phase where a positive center of mass velocity starts and ends
by the take-off (11).

**Procedure**
Prior to data collection all participants had one week of familiarization with the CMJ test
where baseline values were established. The athletes had the opportunity to do the test each
day for one week with each assessment consisting of three trials of the CMJ. The athletes did
an average of 10 ± 4 jumps during this period. The tests were performed according to a
standardized protocol by Hawking Dynamics (see attachment 1). The baseline values were set
during a week of tapering. The training load was relatively low, allowing values close to their
maximal performance to be set. The baseline values were set as follows; JH and RSI-values
were set by taking the result from the best trial to come as close to the athlete’s maximal performance as possible. As the software delivered duration-metrics based on the average data of the three trials of each assessment, the best average value (lowest) was used as the baseline for the duration-values. Baseline for the impulse-metrics were set by taking the average value from every trial. With regard of previous research, CMJ-data were later collected for the analysis of the study using the average value of the three trials. TRIMP-score were calculated from each day and the total TRIMP of the three days prior to the assessment was used in the analysis.

**Statistical analysis**

Pearson’s correlation coefficient was generated between TRIMP and the CMJ-variables using linear regression analysis in JAMOVI (26). P-value for significance were set to < 0.05 and the strength of the correlation were graded according to Hopkins et al. (27); r < 0.1 trivial, 0.1-0.3 = small, 0.3-0.5 = moderate, 0.5-0.7 = large, 0-7-0.9 = very large, >0.9 = nearly perfect. Microsoft Excel (28) was used getting the mean value and standard deviation by using the formulas “=AVERAGE” and “=STDEV”. Scatterplots and descriptive table of the statistics were also formed in Microsoft Excel.

**Ethics**

An information letter about the study was given to all participants explaining the purpose of the study, the meaning of participation, that participation is voluntary and can be withdrawn at any time without giving a reason (see attachment 2). Consent was gathered in two stages to ensure participation was truly voluntary and not due to the athlete’s dependency of the coach. At first in presence of the coach and secondly in written format without the presence of the coach. Henceforth, data collection was conducted in accordance with GDPR meaning that personal information was stored safely without access by unauthorized and all results were presented on group level preventing personal information from being traced to individuals. To ensure that the test was performed as safely as possible, the force plates were mounted on the floor with protective tape around each leg of the force plates to prevent them from moving during the test. During the test, a person was also standing next to the force plates to keep the participants from falling off the plates in case they lost their balance.
Results

Statistics of average three-day-TRIMP over the testing period and the average performance of the CMJ can be found in figure 1. The training load varies during the five weeks with two clear spikes during the second and fourth week. The average change of performance from baseline varies between the trials and between the different variables. The overall smallest change seems to be at the second trial of the second week followed by the greatest decrease in performance during the first trial of week three.

Figure 1. Average variation of Training Load (TRIMP of 3 days prior to test) and average change from baseline-values of different CMJ-variables during each testing day. JH-FT: Jump height – flight time, JH-IM: jump height – impulse, RSI-IM: Reactive strength index – impulse, RSI-FT: Reactive strength index – flight time, B-DUR: Braking duration, P-DUR: Propulsive duration, B-IM: Braking impulse, P-IM: Propulsive impulse

The correlation between the variables and the TRIMP-score are shown in Table 3. JH-FT and JH-IM show the strongest correlations ($r = 0.23$ and $r = 0.24$, $p > 0.05$) while P-DUR and P-IM show no correlation ($r = 0.0$ and $r = 0.02$, $p > 0.05$).
Table 3. Correlation Coefficients of variables of the CMJ and previous three days total TRIMP

<table>
<thead>
<tr>
<th></th>
<th>JH-FT</th>
<th>JH-IM</th>
<th>RSI-IM</th>
<th>RSI-FT</th>
<th>B-DUR</th>
<th>B-IM</th>
<th>P-DUR</th>
<th>P-IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson’s r</td>
<td>0.23</td>
<td>0.24</td>
<td>0.13</td>
<td>0.13</td>
<td>-0.10</td>
<td>-0.11</td>
<td>0.00</td>
<td>0.02</td>
</tr>
<tr>
<td>P-value</td>
<td>0.07</td>
<td>0.06</td>
<td>0.33</td>
<td>0.29</td>
<td>0.42</td>
<td>0.41</td>
<td>0.98</td>
<td>0.90</td>
</tr>
<tr>
<td>Mean</td>
<td>-7.0</td>
<td>-6.6</td>
<td>-12.6</td>
<td>-12.1</td>
<td>17.8</td>
<td>4.6</td>
<td>12.5</td>
<td>3.3</td>
</tr>
<tr>
<td>SD</td>
<td>5.9</td>
<td>5.3</td>
<td>11.9</td>
<td>12.7</td>
<td>13.7</td>
<td>6.4</td>
<td>10.4</td>
<td>5.3</td>
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</table>


Figure 2. show the correlation between JH and training load. JH calculated by flight time and impulse both show a small positive correlation to the TRIMP score with JH-IM showing a slighter stronger correlation (r = 0.24 p = 0.06) than JH-FT (r = 0.23, p = 0.07). RSI-IM and RSI-FT have the same small positive correlation to TRIMP (r = 0.13) (Figure 3). Correlation of the duration-variables can be found in figure 4. B-DUR show a small negative correlation (r = -0.10 p > 0.05) while P-DUR does not show any correlation with the training load (r = 0.00, p > 0.05). B-IM show a small negative correlation (r = -0.11, p > 0.05) and P-IM no correlation (r = 0.02 p > 0.05).

Figure 2. Relationship between Jump Height-variables (change from baseline) and TRIMP (three days prior to CMJ-testing). JH-FT: Jump height – flight time, JH-IM: jump height – impulse,
Figure 3. Relationship between RSI-variables and TRIMP (three days prior to CMJ-testing). RSI-IM: Reactive strength index – impulse, RSI-FT: Reactive strength index – flight time

Figure 4. Relationship between duration-variable and TRIMP (three days prior to CMJ-testing). B-DUR: Braking duration, P-DUR: Propulsive duration
Figure 5. Relationship between impulse-variables and TRIMP (three days prior to CMJ-testing). Braking impulse, P-IM: propulsive – impulse.
Discussion

The aim of the present study was to investigate the use of CMJ and its different variables to monitor fatigue in endurance athletes. The strongest correlation of training load could be seen in jump height, although the correlations were small non-significant positive. Reactive Strength Index also showed a small positive correlation but smaller than JH. Both variables from the braking phase showed a small negative correlation to the training load while the variables from the propulsive phase did not correlate at all with the training load. Neither of the correlations showed significance with a p-value ranging from 0.06 (JH-IM) to 0.98 (P-DUR).

In contrast to previously literature, which has questioned the use of jump height and instead highlighted the possible use of force-time variables to monitor fatigue, the present study shows the two jump height-variables to correlate the strongest with raining load. Previous research has shown RSI to be extremely sensitive to fatigue while this study showed a very small correlation between training load and RSI. Ellis et al., Taylor et al., and Claudino et al., all claim the braking phase to be more altered by training load than the propulsive phase. The findings from this study found comparable results in that, a greater correlation between the two variables of the braking phase compared to the same variables of the propulsive phase (impulse and duration). In contrast with previous research the results of this study show that there is close to no difference between the correlation of jump height calculated by flight time and impulse while RSI showed the exact same correlation between the two calculations methods. At the same time as variables calculated by flight time have been shown to be the most used variable (1), the literature have been highlighting the errors and low reliability the flight time calculation-method may cause (29, 30). Force plates are therefore continued to be ruled out as the gold standard for CMJ-testing (12). Here the findings indicates that when monitoring fatigue, using the average result of three trials, there is no markable difference between the two methods. Although most research favors the use of impulse over flight time, there are also studies supporting these findings. Moir (31), Balsalobre-Fernández et al. (32) and Montalvo. (33) all show high reliability when using the flight time-method to calculate jump height. This could in turn, given the same device is used in every assessment, motivate a continued use of the flight time-method when assessing the CMJ to monitor fatigue. Jump height and RSI were the two variables showing the strongest correlation and are also two variables you can gather despite apparatus. This together with the fact that using flight time
seem as good as using impulse, cheaper and more practical apparatus can be used meaning fatigue monitoring can be simplified. This would allow teams and athletes with less recourses to use the CMJ to monitor fatigue.

**Methodological reflection**

Worth addressing are the methodological limitations this study brings and the difficulty quantifying the training load without a method that can be ruled out as the golden standard. Research agrees that quantifying training load is important to monitor fatigue but the challenges of accuracy in the quantification creates its difficulties. As mentioned before, in many team sports, where the intensity and the complexity of the sport is high, the limiting factors are the inability to quantify load for specific movements such as jump and kicks. Moreover, the fact that many devices ability to correctly quantify load decreases when the speed and intensity increases limits its validity in these sports environments. Another limiting factor of fatigue monitoring in team sports is the fact that other parameters apart from solely training load seem to have a big impact on fatigue (stress, mood etc.). Whereas in endurance sports, such as triathlon, it seems like fatigue occurs almost exclusively as a result of high training load (2). Furthermore, considering endurance sport is more likely to be performed with a consistent speed and intensity, one could argue the fatigue monitoring through training load quantification should not be as challenging as in team sports. Despite this there is still no optimal method identified for quantification of training load in endurance athletes and up to this date is seems like every method have its limitations, including the Lucia’s TRIMP used in this study. Therefore, the use of Lucia’s TRIMP-method in this project should be discussed before assuming the correlation reflects the actual relationship between CMJ and training load.

Lucia’s TRIMP seem to be a well-accepted quantification method for endurance sports. In triathlon, where the training sessions often are based on heart rate and performed with a steady state makes the method suitable for the sport. Furthermore, the Lucia’s TRIMP is a simplified version of the original TRIMP-method and has shown similar validity and reliability as the original method (23) and was for those reasons used in this study. However, Cajuela-Anta & Esteve-Lanao lists several downsides to the method in their paper “Training load quantification in triathlon” (34). First, with it being based on heart rate, makes factors like environment, hydration and temperature an impact on the outcome. Second, the method
cannot quantify load over maximum HR and do not take pause-time into account. At last, the simplification of using only three HR-zone can be misleading, for example the same amount of TRIMP is given when training on anaerobic threshold as maximum anaerobic speed. In this study, training load data defined as minutes spent in each of the three HR-zones was collected by two different coaches. Notable was the fact that the TRIMP-score between the two groups of the two coaches reporting data were surprisingly different, considering they were all elite athletes with similar competition schedules. To gather data in terms of minutes spent in each HR-zone, extreme preciseness is required. This was beyond the author’s control making it impossible to ensure the accuracy of the data used in the study. This could potentially explain the variation of TRIMP between the two coaches reporting the data. Further, an interesting discussion is whether the three events of triathlon; swim, bike and run have different effect on fatigue and should be taken into consideration when monitoring the training load. The athletes of this study had specific HR-zones for each event based on precious gas analysis assessments. This ensured that the sessions were performed with correct intensity making the monitoring more precise. However, the Lucia’s TRIMP-method do not distinguish between the different events and the same amount of TRIMP-score are given despite if the athletes are swimming, biking, or running. For the sake of this study, one could argue that this would have been highly relevant considering running may cause more neuromuscular fatigue on muscles used performing the CMJ and would have shown a bigger impact on jumping performance compared to swimming for example.

Prior to the start of the study the participants baseline values were set. This was done during one week of tapering before a competition. During this period the training load was low, allowing the baseline values to be set as close as possible to their real maximal performance. Even though the athletes were in tapering, they still had training session even though they were easy and few. This means there might be a risk they had fatigue inhibiting their maximal level to be reach when the baseline values were set. To avoid this as much as possible the best values of the best trials were chosen instead of the average that was the method used in the analysis. Another aspect that was considered, was the athletes low experience with the countermovement jump. The week where the baseline values were set also served as a period of familiarization. Each athlete did on average ten jumps during this week, letting them get used to the test and apparatus. This also motivates the use of the best value to set the baseline since all athletes jumped higher in conjunction with them getting more experience. However, if the participants got enough familiarization can be discussed. This because there during were
a few times where the athletes performed better than their baseline values which could have several explanations. A possible reason to this could be insufficient of familiarization prior to the study start meaning they did improve their jumping ability but due to technical adaptations rather than them gaining muscular training adaptations. Another possible explanation for the increased performance could be the fact that the baseline values were not true and that they did in fact have fatigue during the baseline week affecting their performance. Although, this only happened a handful of times and could also be on the bias of measurement errors. This study did not consider any measurement errors by defining a smallest worthwhile change (SWC). This means even small changes from baseline, that could have been a result of measurement error, have been used in the analysis. To standardize the CMJ execution a test protocol was followed. All athletes therefore got the same instructions on how to perform the jump and equal feedback points were given. Furthermore, the participants were informed to wear the same shoes during all trials to minimize the influence of external factors influencing the performance. Factors that could not be standardize in this study were warm-up and time of day of testing. This could not be in consideration due to the athletes training schedules and should be seen as limiting factors of the study.

The high variation of data shown in table 2 indicates the individual athlete’s performance of the CMJ varies a lot on the same testing days, which is interesting considering most of the participants had the same amount of TRIMP. On one hand, assuming CMJ is a measurement of fatigue, the big variation in performance could be explain by individual responses to the same workload. This meaning different athletes would perceive the same amount of stress to the body differently resulting in different amount of fatigue, hence the difference in CMJ-performance. Keeping in mind previous research on CMJ and fatigue, one could argue that CMJ is in fact a good measure of fatigue and that the CMJ may be detect individual response of training load. This could argue that endurance athlete’s fatigue status is better shown in the CMJ than using the TRIMP method and did for this reason show low correlations. On the other hand, one could also argue that the high variation in data simply implies the CMJ do not correlate with training load in endurance athletes and should not be used to monitor fatigue. However, the methodological limitations of not having a golden standard to correlate the CMJ against means the results should be viewed with caution. An approach to overcome this problem for future work, would be to make the correlation analysis between not only one monitoring method, but several. Preferably would be an analysis between methods of both objective and subjective nature, for a deeper comparison of the relationships.
This study was comparing the CMJ to the combine training load the three days prior to the testing day for. This because previous research show neuromuscular fatigue to have a more prolonged origin compared to metabolic fatigue and can last from 24 hours up to four days. CMJ. Ellis et al. show that the decrease in CMJ performance over a week were greatest three days after a game day and Gathercole et al. show moderate decreases in the CMJ after 72 hours (35). Considering the number of participants of this study was relatively low, doing the CMJ two times a week compared to one time a week led to more available data to the analysis which was another reason the three days-method to be used. However, since there is no clear picture of how long neuromuscular fatigue lasts, this method may not be the optimal. An alternative method would be to not only compare the load three days prior to the test, but to involve TRIMP for one, two, four or even a week in the analysis as well. Although, that was beyond the scope of this study but an approach to implement in future study designs.

The statistical analysis of this study was made using Pearson’s correlation coefficient and the variables were used as continuous data. This because the collected data, both TRIMP and CMJ-performance, theoretical could be given in any value. However, since most of the athletes were reported doing the exact same training sessions, leading to the exact same amount of TRIMP in the analysis (see figure 2-5), the categorization of the data as continuous could be discussed. An alternative method would be to categorize the TRIMP-score as ordinal data and use Spearman’s rank correlation coefficient as analysis model. Although, the premise to report any possible TRIMP-score was motivating the use of continuous data in this analysis.

**Ethical and societal reflections**

Prior to the start of this study an ethical application was submitted and approved by Umeå University. The participants of the study were recruited by their coach meaning there was a risk the participation was not completely voluntary, due to the athlete’s dependency to their coach. To prevent this the optionally of participation was strongly emphasized in the information letter. Furthermore, the letter highlighted that they in any moment could withdraw their participation without giving a reason and that would not affect their care or treatment in the future. This project collected personal information such as weight, height and age from the participants. Moreover, data in terms of training load and test results were also collected which for elite athletes at the highest level could be consider as sensitive
information. To make sure no personal data got leaked the data were stored in Microsoft Teams, only accessible from authorized people. Results were later published on group level to minimize the possible risk to track data to individual athletes. However due to the low number of participants this could not be guaranteed, which the participants were informed in the information letter. One big risk with participation of this study was the injury risk when performing the CMJ. Because of the force plates evaluation from the ground and the fact that the plates tended to move during the jump, there was a risk of the athlete falling of the plates leading to foot or ankle injuries. This was prior to the study taken into consideration by encircle the leg of the plates on the ground with a special tape to stop them from moving. Furthermore, one person was standing next to the plates when the tests were performed to stop the athletes from falling in case the force plates were moving during the test. Worth adding is the fact that the movement of the force plates could have altered the athlete’s performance if they did not feel safe during the jump.

The findings of this study indicates that there is no remarkable difference between measurements calculated by flight time or impulse. This motivates the use of the cheaper and more practical apparatus such as mat systems and phone apps instead of the more expensive laboratory apparatus. This together with the fact that previous research proves the CMJ to be valid measurement of fatigue status in team sports makes the future for fatigue monitoring bright. Athletes and teams with less resources surrounding them, such as non-professionally or youth teams, could henceforth implement fatigue monitoring through the CMJ in their practices. By simplifying the procedure more people can take advantage of the benefits that fatigue monitoring brings i.e., performance can be enhanced while injury risk and overtraining syndromes can be minimized. This would not only be beneficial for each team and its success but also from a societal viewpoint. Less injuries and overtraining syndromes would lead to reduced load on the health services, and this combined with the possibility to maximize performance would increase the chance of producing successful elite athletes. Conclusively, the CMJ might be the best solution to monitor fatigue among teams, despite level, and could in long term create a more successful and sustainable sport environment.
Conclusion

The study showed a small correlation between six out of the eight examined variables. JH seem to be the most sensitive variable when determining fatigue status in endurance athletes. Along the lines of previous research this study supports the braking phase to be more sensitive to changes in fatigue compared to the propulsive phase. There seem to be no notable difference between the variables calculated by flight time versus impulse meaning cheaper and more practical apparatus may be as good when testing the CMJ for fatigue purposes. These findings may benefit athletes with less resources surrounding them making the fatigue monitoring easily accessible. The low significance of the results and the methodological limitations of this study encourage more research supporting these finding to be made before making any further conclusions.
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Test protocol – CMJ

Athlete steps onto the force plates
1. Athlete stands still to achieve a quiet phase for accurate calculation of the system weight.
2. On cue, the athlete bends forward at the hip and bends the knees into a squatting position, and then instantaneously transitions to propel upwards into the air
3. The athlete should stick the landing and wait until the test I completed

Key points given to athlete if needed:
• Before the athlete starts the movement, it is essential that a quiet phase is achieved.
  - Make sure the athlete stands as still as possible before the jump and that he or she is not shifting their weight or moving their feet.
  - The athlete should drop straight into the jump with no upward movement.
  - Upward movement before the initial drop (unweighting) will cause the test to fail in many cases
  - Make sure the athlete doesn’t try to pre-load before starting the movement

• Hands on hips
  - Arm swing before the jump can cause the test to fail.
  - Best practices call for hands to be held on hips.
  - If you want to incorporate arm swing, have the athlete stand with their arms straight up in the air during the quiet phase
  - Note that it’s important to keep testing protocol consistent over the course of a season or training program, so if you have a certain way you like the athlete to do the jump, stick with it.

• Stick the landing
  - Having the athlete stick the landing will allow for calculations on time to stabilization and landing stiffness

References
Attachment 2. Information and consent letter

Countermovement jump to monitor neuromuscular fatigue in endurance athletes

Information to the participants
You have been asked to participate in a research project. In this document you will find information about the project and what it means to participate.

What is the project about and why should you participate?
To monitor training load (the amount of stress you put on your body while training) is extremely important not only to optimize your performance but also to avoid injury and overtraining syndromes. The aim of this study is to determine whether the counter movement jump (CMJ) can be used as a measurement of training load in order to effectively monitor the fatigue levels in endurance athletes. You have been asked to participate in this study as you are an endurance athlete with the right resources to be able to contribute extremely valuable information for the benefit of the study.

How does the study work?
To participate in this study, you will have to collect training data (pace, distance and duration) of all your training sessions during 6 weeks. During these weeks we will also do testing of the countermovement jump in the lab once a week with each test taking not more than 10 minutes.

Risks with participating?
Even though there’s an injury risk with all kind of tests the CMJ has a low risk for injury due to its simplicity. Furthermore we are making sure the tests will be performed as safe as possible to minimize the risk of injury.

What will happen with my results?
This project will collect and register information about you.

Information that will be collected does not only include test results and training load data but also information about height, weight, and gender. All information will be collected anonymously and published on group level to minimize the ability to track data to you as an individual. However due to the low number of participants in the study there’s no guarantee it won’t be possible.

The data will be stored in safely with no access from unauthorized on an USB. If you wish your results to be registered in the CAR platform it is possible. When the research project is finished the results from the USB will be deleted.

How will I be informed the results of the study?
To anyone who wish to take part of the final work the paper will be emailed. If you want any additional personal test results you can at any moment contact the responsible researcher.
Participation is optional

Your participation is voluntary and you can choose to withdraw at any time. If you choose not to participate or wish to discontinue your participation, you do not have to give a reason, nor will it affect your future care or treatment.

If you wish to discontinue your participation, please contact the person in charge of the study (see below).

INFORMED CONSENT

I have read the information, understood what it means to be a part of this research study and I voluntarily agree to participate.

☐ Yes

☐ No

Name: _____________________________________________

Signature: _______________________________________

Date: _________________________________________