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69 **ABSTRACT**

70 Increased popularity in the utilization of force plates to measure countermovement jumps
71 (cmjs) for performance monitoring warrants the need for strength and conditioning coaches
72 and sport scientists to better understand its force-time characteristics and the calculation of
73 its associated variables. this article aims to provide information on how to understand and
74 analyze the force-time curve of cmjs in microsoft excel, thus providing practitioners an
75 inexpensive and accessible alternative to readily available software on the market.

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103 **INTRODUCTION**

104 The countermovement jump (CMJ) is a highly-used movement to help coaches determine
105 performance changes (1) and fatigue levels (4,15). Typically jumps are measured using
106 contact mats, linear position transducers (LPTs), photoelectric cells, or smartphone
107 applications, and their associated software. Although these technologies are reliable, cost
108 significantly less than force plates, provide instantaneous results, and are portable, they can
109 constrain testing metrics to absolute outcome measures such as jump height, lower-body
110 power (5,15), and concentric force and velocity through theoretical integration (16). Although
111 these variables are highly relevant to sports performance and perhaps readiness to train,
112 valuable information related to vertical ground reaction force (VGFR) cannot be measured,
113 which can provide details as to how these outcome measures are achieved and an insight into
114 alter-native variables unavailable through the aforementioned.

115

116 Recently, there has been an increased interest in the use of force plates to collect CMJ
117 variables, potentially because of their increase in affordability and accessibility. The caveat to
118 collecting CMJ variables from a force plate is that the practitioner needs a way to process the
119 data, and this may incur additional costs for automated software. An alternative is to process
120 and analyze raw force plate data using Microsoft Excel (or other spreadsheet software) to
121 analyze variables that not only relate to absolute outcome measures but also information
122 relating to the jumper's force capabilities, such as impulse during specific phases of the jump.
123 There-fore, the aim of this study is to assist practitioners in understanding the key CMJ
124 phases by explaining how to define them and calculate them using Microsoft Excel.

125

126 **UNDERSTANDING THE FORCE-TIME CURVE**

127 Before analyzing any data in Microsoft Excel, it is important for coaches and sports scientists
128 to understand the CMJ force-time curve. This will make it easier to understand the key phases
129 from which variables are derived. Figure 1 depicts a typical CMJ force-time curve plotted
130 with force on the “y” axis and velocity on the “x” axis. Before the beginning of the
131 movement, there is a steady stance, or quiet standing, period (“bodyweight” between 0 and
132 “A” in Figure 1; to be discussed later in the article). Once the movement be-gins, impulse
133 (area under the force curve relating to force and time) drops below the bodyweight baseline
134 (Figure 1A and 1B) (11). This is known as the “unweighting phase,” where the athlete begins
135 to flex the knees and hips, and drops their center of mass (COM) causing a downward
136 acceleration, with the end of this phase defined by the lowest velocity before take-off (Figure

137 1C). To over-come this, the athlete now activates their leg musculature and thus, creating an
138 impulse above baseline (bodyweight), although at this point, they are still moving downward.
139 It is when the athlete reaches zero velocity (Figure 1D) or when the impulse above baseline
140 (Figure 1B–D) is equal to the impulse created during the unweighting phase (Figure 1A and
141 1B), the jumper achieves his/her lowest countermovement position. This is termed as the
142 “braking phase,” which is directly followed by the “propulsive phase” exhibited by a rise in
143 peak force (Figure 1D and 1E). The reduction in force after peak force to the point of take-off
144 is denoted in Figure 1G where the jumper’s feet leaves the floor, so that their COM is now
145 higher than it was at the beginning of the jump. At this point, the athlete’s COM has reached
146 zero acceleration and their velocity has peaked just before “flight” (Figure 1F). Once in flight,
147 his/her COM begins to decelerate due to the effect of gravity.

148

149 At this point, the jumper is experiencing zero velocity and is moving neither up nor down,
150 thus depicting the apex of the jump or peak displacement (Figure 1H). The instance of
151 landing occurs when force begins to increase on contact (Figure 1I), with peak landing force
152 depicted as the largest spike after landing (Figure 1J).

153

154 **COLLECTING AND ANALYZING THE DATA**

155

156 ***SETTING UP THE TEMPLATE AND ACCOUNTING FOR SAMPLING FREQUENCY***

157 The template layout depicted in Figure 2 is a simplistic layout to help define key information
158 that dictates the different phases of the jump. Hereafter, the article will refer to cells relating
159 to the template, although any combination of the template can be created to fit the reader’s
160 requirements.

161

162 First, the sampling frequency needs to be converted from hertz (Hz) to time (s). The sampling
163 effectively tells us how many data points are collected in 1 second and will be needed when
164 calculating bodyweight, impulse, velocity, and displacement. The determination of the
165 sampling frequency will be dependent on the force plate’s capabilities, with the thought that
166 higher frequencies will capture more accurate values (i.e., more data points per second) (7);
167 however, practitioners may consider going as low as 200 Hz because values relating to jump
168 performance measures have marginal differences (21.8 to 1.31%) when compared with
169 frequencies as high as 500 Hz (7)

170 Next to the “Sample Frequency” cell (Figure 2, cell K1) insert the frequency at which the
171 jump was collected. Below this cell, the Time point can be defined inserting equation a (Table
172 1) next to the “Time point (s)” cell (Figure 2, K2). The Time point should now auto-calculate
173 when a sampling frequency is entered. As an example, a Sample Frequency of 1,000 Hz will
174 give a data point every 0.001 second.

175

176 ***PROCESSING THE COLUMNS***

177 Before extracting jump phase information, the authors recommend setting up the equations b–
178 g (Table 1) in columns C–H. These columns will process acceleration, velocity,
179 displacement, and power during each Time point and will play a fundamental role in defining
180 the jump phases and extracting variables of interest. Initially “Net Force (N)” needs to be
181 calculated in column C by subtracting the jumper’s bodyweight away from the force pasted in
182 column B. At this point, the value that comes up will be the same as the absolute force
183 because the jumper’s bodyweight has not yet been calculated (this is described in the defining
184 bodyweight section). From the net force column, the “Impulse (N·s)” can be calculated in
185 column D using equation c (Table 1). This is the integration of force and time, and is
186 commonly referred to as the area under the curve. The impulse is calculated as an average of
187 the net force generated over 2 Time points multiplied by time and will help provide
188 information on the total amount of force generated during specific phases of the jump.
189 Previous literature has shown that there are differences in curve characteristics and impulse
190 between skilled and unskilled jumpers (6) as well as strong and weak jumpers (2). More
191 skilled and stronger jumpers are shown to create a greater impulse through exerting higher
192 levels of force over a shorter period of time during the propulsive phase as indicated by an
193 increase in jump velocity and rate of force development (3). This means that they are able to
194 accelerate their mass faster, create a greater take-off velocity, and thus jump higher. Second,
195 shallower countermovements (i. e., end of unweighting to end of braking phase) have also
196 been reported to decrease after strength and power interventions (1,5), suggesting improved
197 ability to use the stretch-shortening cycle.

198

199 Therefore, based on the above, using eccentric and concentric impulse as a variable to
200 monitor performance can provide coaches with information about how outcome measures are
201 achieved, and potentially indicate the nature of change elicited by a training intervention or
202 fatigue. Using the principles of physics, the following equations can be used to calculate
203 columns E–H, respectively:

204

205 Acceleration $a = \frac{F}{m}$ (eq 1)

206 Velocity $V = u + at$ (eq 2)

207 Displacement $s = \frac{1}{2}(v - u)t$ (eq 3)

208 Power $P = FV$ (eq 4)

209

210 Where; a = acceleration, F = force, m = mass, V = final velocity, u = initial velocity, t = time,
211 s = displacement, and P = power.

212

213 The calculation of acceleration conducted in column E (Table 1, equation d), simply divides
214 absolute force by the athlete's mass. Because the athlete's mass has not yet been calculated
215 from the baseline (this is described in the defining bodyweight section), an error, #DIV/0!,
216 may appear in the cell, which will change once mass is defined. Because acceleration has
217 been calculated, it can be integrated to derive velocity using equation 2 as shown above. This
218 is achieved by adding initial velocity to the sum of acceleration multiplied by time (Table 1,
219 equation e). The calculation of velocity plays a significant role in helping to define where the
220 specific phases of the jump occur and therefore plays a pivotal role when extracting variables
221 of interest later. We can then integrate the velocity to obtain displacement, which will be used
222 to help define the landing at a later phase. This is achieved by multiplying 0.5 by the sum of
223 final velocity, minus initial velocity and then multiplying this by the Time point. The Time
224 point in this case will be dependent on the frequency the jump was collected (Table 1,
225 equation f). Power generated through the jump can also be easily calculated by multiplying
226 force and velocity (Table 1, equation g), which allows us to extract power related variables.
227 Because power is a sought-after CMJ metric, this is deemed an important performance factor
228 in time-constrained tasks (13). Peak power, as the names states, is the peak (highest value) of
229 work done within the jump. Much like peak force, this value represents one instantaneous
230 moment in time, equivalent to 1 Hz, and therefore only presents a small portion of the jump.
231 Arguably average power presents a greater portion of the jump and may be able to help
232 coaches decipher what changes have occurred, the jump strategies used, and at which phase,
233 which may be particularly useful where performance is time constrained (i.e., must occur
234 quickly). All equations need to be applied to all rows up to the end of your force and time
235 data. This can easily be performed by highlighting the cells and double clicking the bottom
236 right corner.

237

238

239 ***STEADY STANCE AND DEFINING BODYWEIGHT***

240 Before phase detection, it is important that practitioners understand the value and
241 methodological rigor required to collect CMJ force-time data. To collect reliable and easy-to-
242 analyze data, the plate must be zeroed before the athlete stands on it. Once this is performed,
243 the athlete must adopt the ready position (hands on hips and feet preferred width apart) and
244 stand motionless on the plate for at least 1 second so that bodyweight can be obtained (14).
245 The importance of this is to quantify the jumper's bodyweight by averaging the motionless
246 period, which in turn will enable the detection of the initiation of the jump at a later stage.

247

248 Once data has been collected, check using the data acquisition software to see whether there
249 is a quiet stance of at least 1 second before movement. If large levels of fluctuation are
250 identified in the steady stance, the authors suggest a new trial to be recorded. When happy
251 with the acquired data, transfer it to a text file and copy and paste the time and raw data of the
252 VGRF into cells A2 and B2 of the spreadsheet, respectively. It is suggested to graph these
253 data using a scatter plot with smooth lines to visualize the force-time curve. This helps
254 contextualize the equations that need to be entered into Excel and ensures that data are
255 obtained from the phases of interest.

256

257 Next to "Baseline Start" (Figure 2, cell K3), insert the cell number of where the baseline
258 should start from. Under this, insert equation h (Table 1) which will end the baseline 1 second
259 after the defined start. Remember, this period must have a flat line with minimal fluctuations
260 and be as close to the beginning of the jump as possible (i.e., from when force starts to
261 decrease). It is now possible to find the average force between the 2 baseline markers to
262 compute the athlete's bodyweight. This is performed by entering equation i (Table 1) next to
263 the "Bodyweight (N)" cell and can then be converted into mass (kg) in the "Mass (kg)" cell
264 by simply dividing the value by gravitational force (9.81) (Table 1, equation j).

265

266 ***DEFINING THE START***

267 Defining the start of the jump dictates the accuracy of the variables derived from the CMJ;
268 therefore, using a robust methodology is imperative. Unfortunately, there is no agreed method
269 for determining the initiation of the jump, with previous research defining the initiation using

270 manual inspection, predetermined thresholds based on percentage of bodyweight (10) and 5
271 SD of bodyweight (14).

272

273 In brief, the manual inspection method can be time consuming and is not a viable option for
274 coaches with time constraints, and of course lends itself to human error, and although reliable,
275 the predetermined threshold could very well exclude signals relating to the jump. Identifying
276 the initiation of the jump as the first force value less than 5 SD of bodyweight has been
277 shown to reduce the probability of identifying the incorrect start point (14). To achieve this,
278 bodyweight minus 5 SD needs to be obtained in Excel. In the cell to the right of the “BW - 5
279 SD Value (N),” insert equation k (Table 1). This will effectively subtract 5 SD from body-
280 weight and identify the start of the jump. After this, equations l and m (Table 1) can be used
281 to calculate the row number and associated time point at which “BW - 5 SD Value (N)”
282 occurs, respectively. It is important to understand that at this point, movement has occurred,
283 and the jump has already started; thus, velocity will not be zero. In turn, this can reduce the
284 accuracy of the velocity calculations and affect phase detection and outcome measures such
285 as jump height and power. To calculate an appropriate point at which velocity is likely to be
286 zero, Owens et al. (14), suggested that the point of integration (point when VGRF after signal
287 to jump exceeds $BW \pm 5 SD$) is taken -30 ms from the initiation of the jump (-30 ms from
288 bodyweight - 5 SD). This is out-lined in Table 1 equation n–p, and will therefore start
289 calculating velocity, dis-placement, and power -30 ms from the defined start threshold of
290 BW-5 SD, with greater confidence that velocity is at 0.

291

292 ***FINDING PEAK FORCE***

293 The peak force of the jump refers to the largest force generated before take-off. To compute
294 the end of the un-weighting phase and braking phase, respectively, knowing the row of peak
295 force will act as a reference point, therefore shortening the number of equations required. The
296 peak force row, time, and value can be calculated using equations q–s (Table 1), using a
297 combination of INDEX and MATCH functions. Readers may notice that the value computed
298 in fact relates to the peak landing force. This is due to having not yet calculated the take-off
299 value, of which the “Peak Force Row” equation uses to tell Excel to look for the peak up to
300 the take-off.

301

302 ***FINDING THE END OF THE UNWEIGHTING PHASE***

303 The end of the unweighting phase is defined as when VGRF reaches a value equal to that of
304 the athlete's body-weight (Figure 1B). Because the start threshold of the jump may not exist,
305 it can be difficult to ask Excel to find the same or similar value to define this phase. A good
306 alternative is to use the lowest velocity value (Table 1, equation t), which marks the end of
307 the negative acceleration associated with this phase. Once obtained, the Time point at which
308 this occurs, along with its associated value can be obtained (Table 1, equation u and v,
309 respectively).

310

311 ***FINDING THE END OF THE BRAKING PHASE***

312 The end of the braking phase marks the athlete switching from a predominantly eccentric
313 motion to a predominantly concentric, propulsive motion. This is dictated by velocity
314 reaching 0 and is calculated using equation w (Table 1). Once again, an INDEX function can
315 be used to define the Time point and value of the braking phase (Table 1, equation x and y,
316 respectively). Because velocity starts at 0 and goes into negative values, it is advised that the
317 reader inserts 0.01 as the MATCH number in equation w (8). This will enable this function to
318 search for the first positive value after 0.

319

320 ***PEAK DISPLACEMENT***

321 Peak displacement will provide information on the COM such as its peak. This occurs when
322 velocity reaches zero and will help to later define the landing point within Excel, and thus
323 peak landing force (Table 1, equations z and aa).

324

325 ***TAKE-OFF AND LANDING***

326 Much like defining the start of a jump, many methods have been used to identify take-off.
327 These include: taking the value greater than the peak residual force across a 0.3-second period
328 during the flight phase (12), 5 SD during the flight phase across a 0.3-second period (9), and
329 identifying the first VGRF value under a defined threshold, such as 10 N (13). Because we
330 need to account for any variability produced by noise of either the individual or the force
331 plate the authors suggest using 5 SD of 300-ms flight force, thus reducing the
332 misidentification of take-off. To achieve this, Excel must look for a value less than 10 N in
333 the force array by inserting equation ab (Table 1). It should be noted that Excel may not find
334 exactly 10 N; therefore, the -1 in the equation will look for the smallest value in the array
335 selected (in this case, the force column) that is equal to or greater than 10 N. Once the take-

336 off row is defined, the time and value of take-off can be computed using equations ac and ad,
337 respectively (Table 1).

338

339 Once this has been performed, the landing row, time, and force value can be calculated (Table
340 1, equations ae, af, and ag, respectively). This is calculated using a match function looking for
341 a value greater than 10 N between peak displacement and peak landing force. Now that take-
342 off and landing have been defined, a threshold using 5 SD needs to be calculated for both
343 phases. Previous literature (9,12) have used an arbitrary unit of 300 ms from take-off to
344 calculate the 5 SD thresh-olds because a meaningful change in the force can be detected that
345 best rep-resents the take-off and that falls out-side the noise of the force plate. Second, 300
346 ms is a long enough time in that it measures a substantial amount of the flight time, given that
347 most individuals will have a flight time greater than 300 ms. When inserting the equations ah
348 and aj (Table 1), readers should be cautioned that the value 300 relates to 300 ms based off of
349 the 1,000 Hz the example data were collected at. Therefore, should the reader collect jumps at
350 a different frequency, then it is recommended that this figure is altered so it represent 300 ms
351 (i.e., 500 Hz = 150). On completion, the time at which take-off and landing 5 SD occurs can
352 be calculated using equations ak and al (Table 1), respectively.

353

354 **SETTING UP POINTS OF INTEREST**

355

356 Now that the spreadsheet functions can detect the start and end of key phases, it is useful to
357 present this in a graphical format (Figure 3). The authors suggest this for 2 reasons; (a) it
358 allows coaches to see whether the phases are in the correct place and allows for any
359 corrections to be made in the template if the points are incorrect relative to Figure 1. First and
360 foremost, a scatter plot graph needs to be inserted by selecting column B, going to the
361 “Insert” tab and selecting “scatter with smooth lines” under “charts.” Next, the point of
362 interest (POI) can be inserted, which include but are not limited to; Start, end of un-
363 weighting, end of braking, and take-off. This requires the use of an offset function, which will
364 help define the specific POI in the force-time curve. In cell K9, next to “BW - 5SD Row”,
365 type the following formula; = OFFSET(B2, K9,0), where B2 is the start of the Fz column, K9
366 is the start of row cell number, and 0 is the column. This needs to be repeated for each POI
367 replacing K9 with its respective row cell number (i.e., end of unweighting is K15). From
368 here, the POI can be added onto the graph by right clicking the graph and selecting “Select
369 data..” In the pop up, select “Add” and select the series name, X value (row number), and Y

370 value (offset value) for each POI. Once complete, some editing is required to highlight these
371 points. This is achieved simply by right clicking the chart and selecting “Change chart type.,”
372 selecting “Combo,” and altering the Fz series to “Scatter with smooth lines” and all series
373 relating to the POI as “Scatter.” Note that the “secondary axis” box for the POI should be
374 unchecked. The POI colors can be edited to the reader’s requirements. To add a key, click on
375 the graph and go to “quick layout” found under the “Design” tab and select the most
376 convenient layout.

377

378 **TYPICAL VS ALTERNATIVE VARIABLES**

379

380 Now that the template is set up, it is possible to extract variables of interest. A range of
381 variables can be obtained from CMJ VGRF, and are generally categorized as “typical” and
382 “alternative,” as outlined in Table 2 (4,5). Typical variables refer to commonly used outcome
383 measures that relate to absolute values for the concentric portion of the jump (i.e., jump
384 height and peak power). Although these variables are easy to obtain, they may overlook key
385 components within the jump, which may help better explain altered jump strategies during
386 fatigue or changes in temporal force-time characteristics after an intervention. For example,
387 the shape of the curve has been shown to change after a periodized program of strength and
388 power training (5), as well as power-only interventions (1). The outcome elicited a shallower
389 counter-movement, steeper rise in force during the braking phase, and a higher peak force,
390 with concurrent increases in peak power and take-off velocity, and consequently, jump
391 height. However, Cormie et al. (1), concluded that peak performance variables, such as peak
392 power and peak force, offer little insight into how adaptations have occurred; thus, examining
393 changes in temporal force and power may help coaches more clearly understand the type of
394 change elicited from an intervention. It is for this reason that alternative variables have gained
395 attention because they may provide a better insight into neuromuscular-related changes
396 relating to contraction times (e.g., eccentric contraction time and concentric contraction time)
397 and force-velocity relationships (e.g., force at zero velocity and force-velocity area under
398 curve). Furthermore, given this greater insight into neuromuscular function, sensitivity to
399 change can be explored in greater depth, thus allowing coaches to understand the level and
400 magnitude of changes occurring, and more specifically, at what phase they occur. The authors
401 have presented Excel equations in Table 3 for some common variables that best describe
402 jump characteristics.

403

404 **CONCLUSION**

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It is important that coaches understand the constituent parts of the CMJ force-time curve before processing force-time data and extracting variables that may be used to detect performance changes or readiness to train. It can help coaches understand why it is important to calculate key variables, using the most robust and easy-to-apply methods, within the confines of day-to-day practice. Although peak values and averages relating to concentric data are highly reliable in field-based technologies, the underpinning determinants of these factors are influenced by a pre-stretch during the eccentric phase, of which the information is only obtainable through force-time data. Second, the time taken during each phase could also give coaches an insight into altered jump strategies. It should additionally be noted that with recent advances in technology, more portable and affordable force plates have become available, enabling coaches greater access to CMJ performance variables. Therefore, if viable, the authors suggest that force plates be used to assess CMJ. This is primarily due to their ability to not only detect and monitor underpinning changes in CMJ performance, but also to better inform training prescription and the understanding of training adaptation.

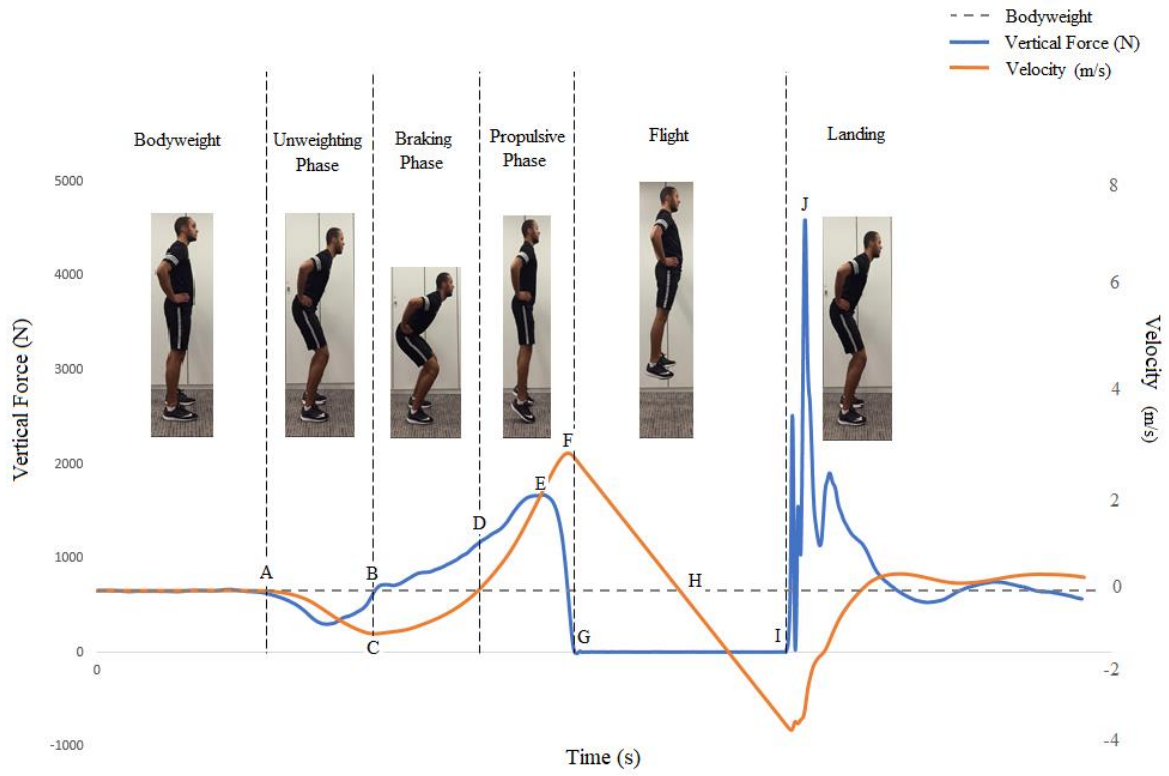
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Figure 1. Force- and velocity-time characteristics of a countermovement jump.

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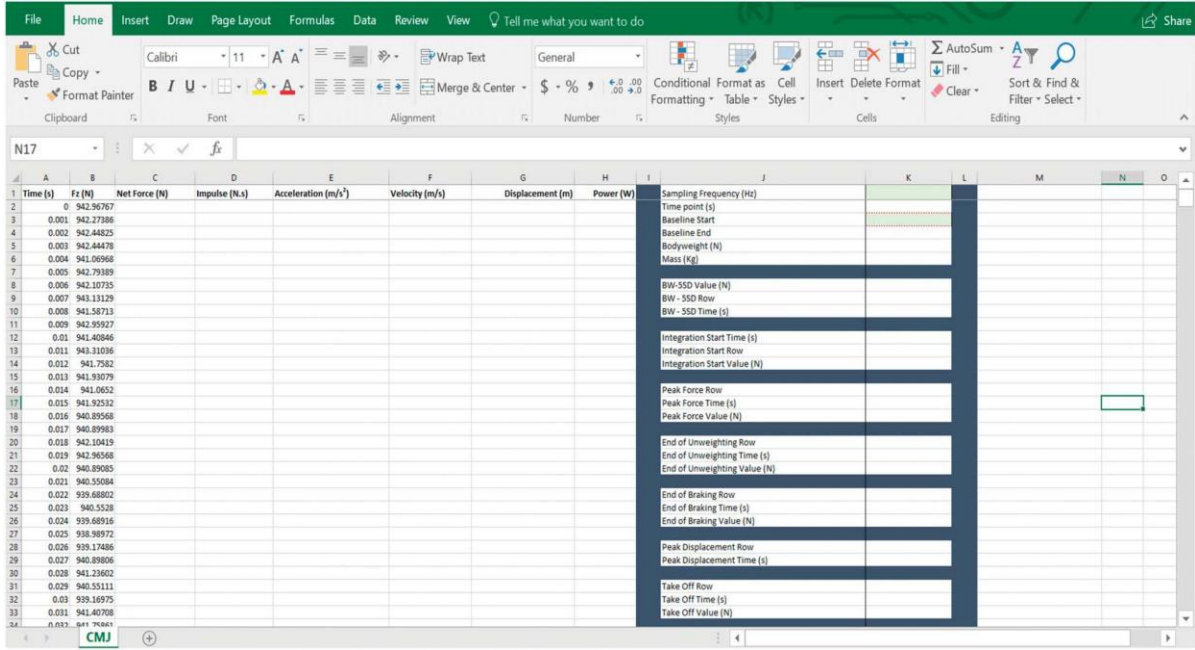


Figure 2. Excel template layout.

615 **Table 1.** Equations to calculate specific phases and variables pertaining to the CMJ in Microsoft Excel.

Cell Name	Equation	Excel calculation
Time	Copy and pasted from the raw data extracted from the force time curve.	
Force (N)		
a. Time point	= 1/ sample frequency	= 1/\$K\$1
b. Net Force (N)	= Force – bodyweight	=B2-\$K\$5
c. Impulse*	= (Average of current row and previous row of net force) * (1/sample frequency)	=(AVERAGE(C2:C3))*(1/\$K\$1)
d. Acceleration	= Net force / mass	= C2/\$K\$6
e. Velocity*	= IF(time point is >integration start time, SUM(velocity from above+(acceleration of row below*time point)), "0.00")	=IF(A3>\$K\$12,SUM(F2+(E3*\$K\$2)), "0.00")
f. Displacement*	= displacement from prior cell+(velocity of current row*(1/sample frequency))	=G2+(F3*(1/\$K\$1))
g. Power*	=IF(time point is >integration start time, Fz*integrated velocity, "0.00")	=IF(A3>\$K\$12,B3*F3, "0.00")
h. Baseline End (1 second)	= baseline start + sample frequency	= K3 + \$K\$1
i. Bodyweight (N)	= AVERAGE (INDEX (force array, baseline start): INDEX (force array, baseline end))	=AVERAGE(INDEX(B:B,K3):INDEX(B:B,K4))

j. Mass (kg)	= bodyweight/gravity	=\$K\$5/9.81
k. BW – 5SD Value (N)	= bodyweight- (5*STDEV.P(INDEX (force array, baseline start):INDEX(force array, baseline end))))	=K5-(5*STDEV.P(INDEX(B:B,K3):INDEX(B:B,K4)))
l. BW – 5SD Row	= MATCH(BW-5SD value, force array, -1)	=MATCH(K8,B:B,-1)
m. BW – 5SD Time (s)	= INDEX(time array, start row)	=INDEX(A:A,K9)
n. Integration Start Time (s)	= BW – 5SD time (s) – 0.03	=K10-0.03
o. Integration Start Row	=MATCH(Integration start time, time array, 1)	=MATCH(K12,A:A,1)
p. Integration Start Value (N)	=INDEX(net force array, integration start row)	=INDEX(B:B,K13)
q. Peak Force Row	=MATCH(MAX(INDEX(force array, first force cell):INDEX(force array, take off row cell)), force array, 0)	=MATCH(MAX(INDEX(B:B,B2):INDEX(B:B,K31)),B:B,0)
r. Peak Force Time (s)	=INDEX (time array, peak force row)	=INDEX(A:A,K16)
s. Peak force Value (N)	=INDEX (force array, peak force row)	=INDEX(B:B,K16)

t. End of Unweighting Row	=MATCH(MIN(INDEX(velocity array,1):INDEX(velocity array, peak force row)),INDEX(velocity array,1):INDEX(velocity array, peak force row),0)	=MATCH(MIN(INDEX(F:F,1):INDEX(F:F,K16)),INDEX(F:F,1):INDEX(F:F,K16),0)
u. End of Unweighting Time (s)	=INDEX(time array, end of unweighting row)	=INDEX(A:A,K20)
v. End of Unweighting Value (N)	=INDEX(force array, end of unweighting row)	=INDEX(B:B,K20)
w. End of Braking Row	=MATCH(0.01,INDEX(velocity array,1):INDEX(velocity array, peak force row),1)	=MATCH(0.01,INDEX(F:F,1):INDEX(F:F,K16),1)
x. End of Braking Time (s)	=INDEX(time array, end of braking row)	=INDEX(A:A,K24)
y. End of Braking Value (N)	=INDEX(force array, end of braking row)	=INDEX(B:B,K24)
z. Peak Displacement Row	=MATCH(MAX(displacement array), displacement array,0)	=MATCH(MAX(G:G),G:G,0)
aa. Peak Displacement Time (s)	=INDEX(time array, peak displacement row)	=INDEX(A:A,K28)

ab. Take off Row	=MATCH(10,force array,-1)	=MATCH(10,B:B,-1)
ac. Take off Time (s)	=INDEX(time array, take off row)	=INDEX(A:A,K31)
ad. Take off Value (N)	=INDEX(force array, take off time)	=INDEX(B:B,K31)
ae. Landing Row	=MATCH(10,INDEX(force array,peak displacement row):INDEX(force array,(MATCH(MAX(force array),force array,0))),1)+peak displacement row	=MATCH(10,INDEX(B:B,K28):INDEX(B:B,(MATCH(MAX(B:B),B:B,0))),1)+K28
af. Landing Time (s)	=INDEX(time array, landing row)	=INDEX(A:A,K35)
ag. Landing Value (N)	=INDEX(force array, landing row)	=INDEX(B:B,K35)
ah. Take off/Landing Threshold 5SD (N)	=AVERAGE(INDEX(force array,(take off row+300)):INDEX(force array,(landing row-300)))+(5*STDEV.P (INDEX(force array,(take off row+300)):INDEX(force array,(landing row -300))))	=AVERAGE(INDEX(B:B,(K31+300)):INDEX(B:B,(K35-300)))+(5*STDEV.P(INDEX(B:B,(K31+300)):INDEX(B:B,(K35-300))))

ai. Take Off Row 5SD	=MATCH(take off/landing threshold, force array, -1)	=MATCH(K39,B:B,-1)
aj. Landing Row 5SD	=MATCH(take off/landing threshold, INDEX(force array,(take off row 5SD+300)):INDEX(force array,(MATCH(MAX(force array),force array,0))),1)+(take off row 5SD+300)	=MATCH(K39,INDEX(B:B,(K40+300)):INDEX(B:B,(MATCH(MAX(B:B),B:B,0))),1)+(K40+300)
ak. Take Off Row 5SD Time (s)	=INDEX(time array, take off row 5SD)	=INDEX(A:A,K40)
al. Landing Row 5SD Time (s)	=INDEX(time array, landing row 5SD)	=INDEX(A:A,K41)

616 *next to the variables name means add the equation in the cell below, and input 0 in the cell above.

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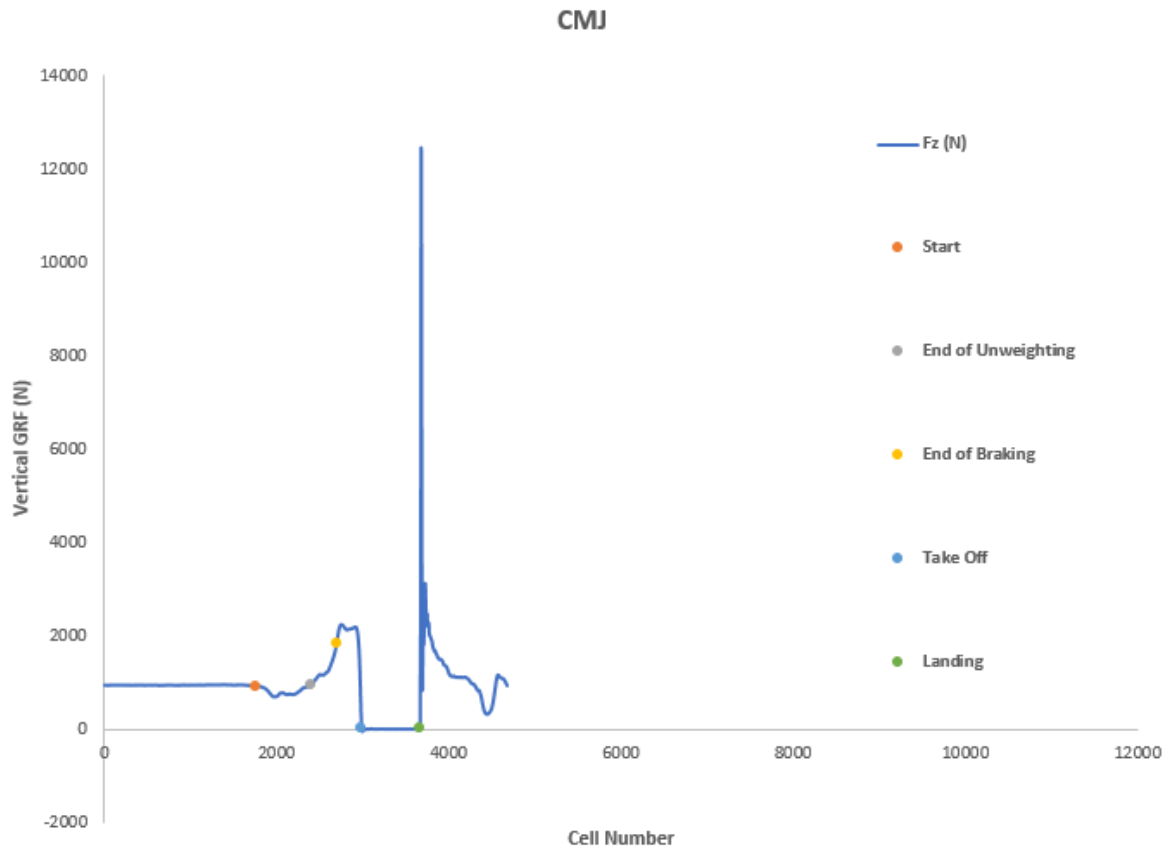
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 632 **Figure 3.** Graphical representation of VGRF data with points of interest. CMJ =
 633 countermovement jump; GRF = ground reaction force.

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658 **Table 2** – Typical and alternative variables previously obtained from ground reaction force data of CMJ’s.

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Typical variables	Unit	Variable Definitions
Mean power	W	<i>peak concentric power / time of concentric phase.</i>
Maximum rate of power development	W/s	<i>largest power increase during a given time frame (ie, 30-ms)</i>
Time to peak power	s	<i>time it takes from the beginning of the propulsion phase to peak power</i>
Mean force	N	<i>peak concentric force / time of concentric phase</i>
Maximum rate of force development	N/s	<i>largest force increase during a given time frame (ie, 30-ms)</i>
Time to peak force	s	<i>time it takes from the beginning of the propulsion phase to peak force</i>
Relative net impulse	Ns/Kg	<i>total impulse / jumpers body mass</i>
Peak velocity	m/s	<i>fastest vertical speed of the centre of mass</i>
Minimum velocity	m/s	<i>slowest vertical speed of the centre of mass</i>
Velocity at peak power	m/s	<i>speed of the centre of mass at the point of peak power</i>
Flight time	s	<i>landing time – take off time</i>
Flight time: contraction time	-	<i>ratio of flight time to contraction time</i>
Alternative Metrics	Unit	Metric Calculations and Definitions
Force at 0 velocity	N	<i>force when velocity is zero (transition from eccentric to concentric)</i>

Force velocity – area under curve	N/ms^2	<i>area under the curve during eccentric phase</i>
Eccentric duration	s	<i>time of eccentric contraction during the countermovement</i>
Concentric duration	s	<i>time of concentric contraction during the jump</i>
Total duration	s	<i>eccentric + concentric duration</i>
Mean eccentric and concentric power over time	$W \cdot kg^{-1} \cdot s^{-1}$	<i>power during eccentric and concentric phase / total duration</i>
Reactive strength index modified	-	<i>jump height/time to take off</i>

660 W = Watts, W/s = Watts per second, N = Newtons, Ns = Newtons per second, m/s = meters per second, s = seconds, Ns/Kg = Newtons per
661 second, per kilogram, $W \cdot kg^{-1} \cdot s^{-1}$ = Watts per kilo, per second.

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679 **Table 3** – Metrics obtainable from ground reaction force data of a CMJ.

Cell Name	Equation	Excel Calculation
a. Eccentric Impulse (Ns)	=SUM(INDEX(impulse array, end of unweighting row):INDEX(impulse array, end of braking row))	=SUM(INDEX(D:D,K20):INDEX(D:D,K24))
b. Concentric Impulse (Ns)	=SUM(INDEX(impulse array, end of braking row):INDEX(impulse array, take off row 5SD))	=SUM(INDEX(D:D,K24):INDEX(D:D,K40))
c. Duration of Eccentric Impulse (s)	= end of unweighting time – BW-5SD time	=K21-K10
d. Duration of Concentric Impulse (s)	= end of braking time – take off 5SD time	=K32-K25
e. Jump Height (m)	=SUM(MAX(velocity array)^2)/(2*gravity)	=SUM(MAX(F:F)^2)/(2*9.81)
f. Peak Force (N)	=peak force value - bodyweight	=K18-K5
g. Peak Power (W)	=MAX(INDEX(power array, integration start row):INDEX(power array,take off row 5SD))	=MAX(INDEX(H:H,K13):INDEX(H:H,K40))
h. Eccentric Avg. Power (W)	=AVERAGE(INDEX(power array,integration start row):INDEX(power array,end of braking row))	=AVERAGE(INDEX(H:H,K13):INDEX(H:H,K24))
i. Concentric Avg. Power (W)	=AVERAGE(INDEX(power array,end of braking row):INDEX(power array,take off row 5SD))	=AVERAGE(INDEX(H:H,K24):INDEX(H:H,K40))

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681 W = Watts, N = Newtons, Ns = Newton per second, m = meters, s = seconds