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1 **The effects of relative trunk rotation velocity on ball speed and elbow and**
2 **shoulder joint torques during baseball pitching**

3
4 Yousuke Tanaka^a, Tomoya Ishida^{a*}, Takumi Ino^b, Yuki Suzumori^a, Mina
5 Samukawa^a, Satoshi Kasahara^a, and Harukazu Tohyama^a

6
7 ^a *Faculty of Health Sciences, Hokkaido University, Sapporo, Japan*

8 ^b *Faculty of Health Sciences, Hokkaido University of Science, Sapporo, Japan*

9
10 *Corresponding Author

11 Tomoya Ishida

12 E-mail: t.ishida@hs.hokudai.ac.jp Faculty of Health Science, Hokkaido University, North 12,
13 West 5, Kitaku, Sapporo 060-0812, Japan.

14
15 ORCID

16 Tomoya Ishida <https://orcid.org/0000-0003-0174-7416>

17 Mina Samukawa <https://orcid.org/0000-0002-4663-598X>

20 **ABSTRACT**

21 In baseball pitching, suppressing trunk rotation while rotating the pelvis in the early phase of
22 arm cocking is important for throwing a fast ball. However, quantitative evaluation of trunk
23 rotation during pitching has not been established, and its associations with elbow and
24 shoulder torques are unclear. The purpose of this study was to examine the correlation of a
25 new measure of trunk rotation suppression with ball speed and elbow and shoulder torques
26 during pitching. Eighteen adult male baseball pitchers (21.7 ± 1.2 years old) participated.
27 Three qualified pitches were analysed using a three-dimensional motion capture system.
28 Trunk rotation velocity, normalised to the peak velocity, was derived at the time of peak
29 pelvic velocity. Pearson's correlation coefficient was used to determine correlations. The
30 normalised trunk rotation velocity at the peak pelvic velocity was significantly correlated
31 with elbow valgus torque ($R = -0.508, P = 0.032$), shoulder external rotation torque ($R = -$
32 $0.507, P = 0.032$) and ball speed ($R = -0.504, P = 0.033$). A smaller normalised trunk rotation
33 angular velocity at the time of peak pelvic rotation velocity could increase ball speed but may
34 also increase elbow and shoulder torques among pitchers who demonstrate trunk rotation
35 after foot contact.

36

37 **Keywords:** baseball pitching; trunk rotation movement; ball speed; shoulder external
38 rotation; elbow valgus

39 **INTRODUCTION**

40 Elbow and shoulder injuries are common among baseball players at all ages and skill levels
41 (Dick et al., 2007; Posner et al., 2011; Takagishi et al., 2017; Takagishi et al., 2019; Wasserman
42 et al., 2019), although pitchers have higher incidence rates of elbow and shoulder injuries and
43 undergo more surgeries than fielders (Chalmers et al., 2019; Fares et al., 2020). Elbow and
44 shoulder injuries among pitchers have been reported to include ligament injuries and muscle
45 strains (Fares et al., 2020; Saper et al., 2018). These injuries are mostly caused by overuse
46 mechanisms involving external loads, such as elbow valgus and shoulder external rotation
47 torques (Agresta et al., 2019; Anz et al., 2010; Sabick et al., 2004). Repetitive elbow valgus
48 torque during pitching strains the ulnar collateral ligament, which is the primary ligamentous
49 stabiliser of the medial elbow (Ahmad et al., 2013; Hattori et al., 2021), and excessive shoulder
50 external rotation torque could cause shoulder injury (Fleisig et al., 1996).

51 Large elbow and shoulder torques are associated with trunk rotation as well as faster
52 ball speeds (Aguinaldo et al., 2007; Davis et al., 2009; Fleisig et al., 1999; Fleisig et al., 2006;
53 Hurd et al., 2012). Pitchers who initiated trunk rotation relative to the pelvis before foot contact
54 showed significantly larger elbow valgus torques and shoulder internal rotation torques than
55 pitchers who initiated trunk rotation after foot contact (Aguinaldo et al., 2007; Aguinaldo et al.,
56 2009; Davis et al., 2009). In fact, early trunk rotation before foot contact was associated with
57 an increased risk of elbow and shoulder injuries (Douoguih et al., 2015). Therefore, evaluation

58 and modification of the onset of trunk rotation motion are important for the prevention of elbow
59 and shoulder injuries in pitching. However, the sequence of the peak pelvic and trunk rotation
60 velocities is also important for pitching (Putnam, 1991; Stodden et al., 2006). In the pitching
61 motion, the appropriate sequence of the peak pelvic and trunk rotation velocities enhances the
62 efficiency of transferring the momentum produced by the lower limbs to the ball through the
63 pelvis, trunk, and upper limbs and increases ball speeds (Putnam, 1991; Stodden et al., 2006).
64 Therefore, the pelvic and trunk rotation velocities during the arm-cocking phase may also be
65 associated with elbow and shoulder torques.

66 The evaluation of pelvic and trunk rotation during the arm-cocking phase has been
67 investigated mainly in terms of their association with ball speeds in pitching (Graaff et al.,
68 2018; Sgroi et al., 2015; Urbin et al., 2013). Having the trunk remain facing the third base while
69 the pelvis rotates and faces the home plate for a right-handed pitcher was significantly
70 associated with a faster ball speed (Sgroi et al., 2015). The time length between the peak pelvic
71 and trunk rotation velocities was devised to evaluate the sequence of the pelvic and trunk
72 rotation velocities (Graaff et al., 2018; Urbin et al., 2013). However, the relationships of this
73 time length and ball speeds are inconsistent (Graaff et al., 2018; Urbin et al., 2013). A longer
74 time between the peak pelvic and trunk angular velocity was significantly associated with faster
75 throwing hand speed (Graaff et al., 2018), whereas another study reported that this time length
76 was not associated with a faster ball speed (Urbin et al., 2013). Therefore, it has not been

77 established how to quantitatively evaluate pelvic and trunk rotation velocities during the arm-
78 cocking phase. Furthermore, the associations of pelvic and trunk rotation velocities with elbow
79 and shoulder torques are unclear.

80 As a new evaluation of pelvic and trunk rotation velocities during the arm-cocking
81 phase, we normalised the trunk rotation angular velocity by its peak value. A smaller
82 normalised trunk rotation velocity at the peak pelvic rotation angular velocity represents the
83 degree to which the trunk rotation velocity is suppressed when the pelvis is rotating at the peak
84 velocity, whereas a larger normalised trunk rotation velocity at the peak pelvic rotation angular
85 velocity indicates that the trunk and pelvis rotate simultaneously. Therefore, the normalised
86 trunk rotation velocity at peak pelvic rotation angular velocity could represent the pelvic and
87 trunk rotation movement sequence during the arm-cocking phase (Putnam, 1993; Stodden et
88 al., 2006).

89 The purpose of this study was to examine the relationship of the normalised trunk
90 rotation velocity with ball speed and elbow and shoulder torques during pitching. It was
91 hypothesised that the normalised trunk rotation velocity at the peak pelvic rotation velocity
92 would be positively correlated with elbow valgus torque and shoulder external rotation torque
93 and negatively correlated with ball speed.

94

95 MATERIALS AND METHODS

96 Participants

97 To determine the sample size, an intermediate power analysis was performed using 80%
98 power, an α level of 0.05, and an effect size of 0.6 (G*Power 3.1., Institute of Experimental
99 Psychology, Heinrich Heine University, Dusseldorf, Germany). The assumed effect size was
100 based on the results of our pilot study. According to the results of the power analysis, a
101 sample size of 17 was needed. A total of 18 male pitchers playing in a competitive baseball
102 team participated in this study (13 collegiate and 5 regional baseball team pitchers; age, 21.7
103 \pm 1.2 years; height, 174.7 \pm 6.1 cm; body mass, 73.2 \pm 7.7 kg) (Table 1). The inclusion
104 criteria were pitchers who were overhand throwers, had played for at least 2 baseball seasons
105 and were aged between 18 and 25 years (not including high-school players). The mean
106 pitching experience was 7.9 \pm 3.5 years. All participants had been pitchers for at least 2
107 baseball seasons, and the mean pitching experience was 7.9 \pm 3.5 years. The exclusion
108 criteria were any elbow or shoulder injury in the last 6 months or a history of upper-limb or
109 trunk surgery. Based on a previous study (Olsen et al., 2006), elbow or shoulder injury was
110 defined as (1) shoulder or elbow pain lasting more than 2 weeks, (2) shoulder or elbow pain
111 that caused them not to play in a game or practice, or (3) recurrent shoulder or elbow pain.
112 The participants were recruited on a voluntary basis through posters posted at the university
113 gymnasiums or announcements from the regional amateur baseball association. Written

114 informed consent was obtained from all participants before participation. The present study
115 was approved by the Institutional Review Board at Institutional Review Board of Faculty of
116 Health Sciences, Hokkaido University (approval number: 19-110).

117

118 **Instrumentation**

119 A three-dimensional motion capture system (Vicon MX, Vicon Motion Systems, Oxford, UK)
120 was used to capture the movement. Fourteen infrared cameras (Vantage camera, Vicon
121 Motion Systems) were used to track reflective markers attached to the participant at a rate of
122 200 Hz. Two force plates (OR6, AMTI, Watertown, MA, USA) planted and fixed on the floor
123 were used to record ground reaction forces from the stride foot at 1,000 Hz, and the force
124 data were synchronised with the kinematic data. A radar gun (SGR110, SSK Corp., Osaka,
125 Japan) was used to record ball speed.

126

127 **Procedures**

128 Data collection took place inside a research laboratory. The participants were given enough
129 time to warm up as they normally would before practice or games (e.g., jogging, stretching,
130 warm-up throws). Then, 35 reflective markers were placed on the spinous process of the
131 seventh cervical vertebra (C7), spinous process of the tenth thoracic vertebra (Th10), sternal
132 notch, xiphoid process, head, bilateral acromia, lateral epicondyles of the humerus, radial

133 processes, ulnar processes, second metacarpal on the hands, anterior superior iliac spines
134 (ASIS), posterior superior iliac spines (PSIS), lateral femoral epicondyles, thighs, lateral
135 malleoli, shanks, second metatarsal heads, and heels. The markers on the nonthrowing hand
136 and both feet were placed over the estimated locations on a glove or on shoes, respectively.
137 All participants used the glove or shoes that they usually wore.

138 Once all markers were placed, the participants practised pitching until they were
139 ready to pitch at maximum effort. Pitching was performed on the flat floor towards a circular
140 pitching target with a diameter of 0.3 m placed 10 m from the pitching line at a height of 0.8
141 m from the floor. For the pitching trials, the participants pitched fastballs from the set
142 position. The participants were instructed to pitch as fast and as accurately as possible while
143 aiming at the target. The participants continued to pitch until a minimum of 3 qualified
144 pitches were captured. As a result, participants pitched from 3 to 6 fastballs. The participants
145 were allowed to rest between pitches if needed.

146

147 **Data Processing and Reduction**

148 Kinematics and kinetics were analysed using Vicon Nexus automatic digitization software
149 (version 2.1; Vicon Motion Systems). Raw three-dimensional marker coordinate data were
150 filtered through a Woltring filter using a cut-off frequency of 10 Hz (Anz et al., 2010).
151 Kinematics were calculated using the Cardan sequence (flexion/extension,

152 adduction/abduction, and internal/external rotation). Angles of the pelvis and trunk were
153 calculated relative to the laboratory coordinate system. The segment coordinate systems were
154 defined based on the Vicon Plug-in Gait marker configuration. The origin of the pelvic
155 coordinate system was located at the midpoint of the bilateral ASIS markers (Davis et al., 1991).
156 The Y-axis of the pelvic coordinate system was oriented from the right ASIS marker to the left
157 ASIS marker. The X-axis of the pelvic coordinate system was oriented forwards from the
158 midpoint of the bilateral PSIS markers to the origin of the coordinate system. The Z-axis was
159 oriented upwards, perpendicular to the Y- and X-axes. The origin of the thoracic coordinate
160 system was located at the sternal notch with an offset of half a marker diameter (7 mm)
161 backwards along the X-axis, defined as the direction from the midpoint of C7 and T10 to the
162 midpoint of the sternal notch and xiphoid process. The Z-axis for the thorax was oriented
163 upwards, defined as the direction from the midpoint of the xiphoid process and T10 to the
164 midpoint of the sternal notch and C7. The Y-axis was oriented leftwards, perpendicular to the
165 X- and Z-axes. To define the coordinate systems of the humerus and forearm, three virtual
166 markers of the shoulder, elbow, and wrist joint centres were calculated. The virtual marker of
167 the shoulder joint centre was calculated by shifting the acromion marker downwards by the
168 shoulder offset value. The downwards direction was perpendicular to the line from the thoracic
169 origin to the acromial marker and the X-axis of the thoracic coordinate system. The offset value
170 was the distance between the acromion and the humeral head centre measured by the same

171 physical therapist (T.I.) for each participant, plus half the marker diameter (7 mm). The virtual
172 marker of the elbow joint centre was calculated by shifting the lateral epicondylar marker
173 medially by the elbow offset value. The direction of shifting was determined such that a line
174 from the elbow joint centre to the shoulder joint centre and a line from the elbow joint centre
175 to the lateral epicondylar marker were perpendicular on the plane that was defined by the
176 shoulder joint centre, elbow marker and the construction vector. The construction vector was
177 perpendicular to the plane defined by the shoulder joint centre, the elbow marker, and the
178 midpoint of the two wrist markers and passed through the elbow marker. The elbow offset
179 value was half the distance between the lateral and medial epicondyles of the humerus
180 measured by the same physical therapist (T.I.) for each participant, plus half the marker
181 diameter (7 mm). The virtual marker of the wrist joint centre was offset towards the palmar
182 side from the midpoint of the two wrist markers along a line perpendicular to both the line
183 connecting the two wrist markers and a line from the midpoint of the two wrist markers to the
184 elbow joint centre. The wrist offset value was half the thickness of the wrist measured by the
185 same physical therapist (T.I.), plus half the marker diameter (7 mm). The origin of the humeral
186 coordinate system was located at the elbow joint centre, and the Z-axis was defined as the
187 direction from the elbow joint centre to the shoulder joint centre. The Y-axis for the humerus
188 was a cross product between the Z-axis and the line between the elbow joint centre and the
189 wrist joint centre. The X-axis was the direction perpendicular to the Y- and Z-axes. The origin

190 of the forearm coordinate system was located at the wrist joint centre. The Z-axis was the
191 direction from the wrist joint centre to the elbow joint centre. The Y-axis was defined as the Y-
192 axis of the humerus segment. The X-axis was perpendicular to the Y- and Z-axes.

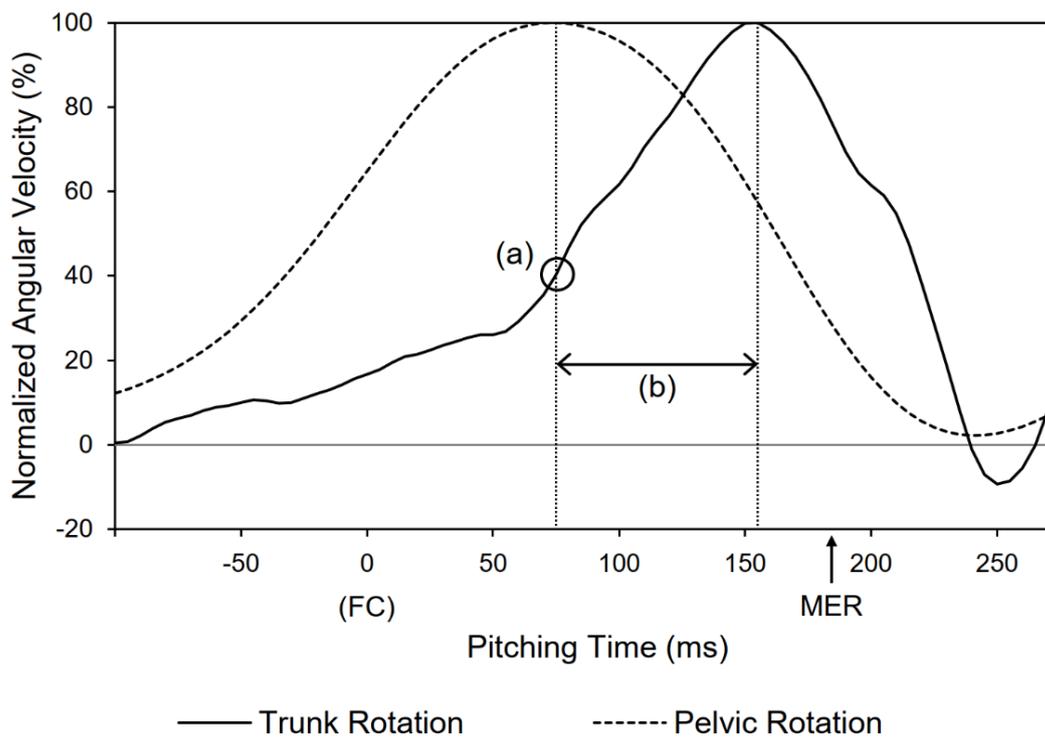
193 The external joint torques of the elbow and shoulder were calculated by inverse
194 dynamics analysis (Winter, 1980). The arm-cocking phase was defined as the time from foot
195 contact to maximum shoulder external rotation (Fleisig et al., 1996; Fleisig et al., 2006). Foot
196 contact was identified as the instant when the vertical ground reaction force from the front foot
197 exceeded 10 N (Oyama et al., 2014).

198 Following data reduction, the peak angular velocities of the axial rotation of the pelvis
199 and trunk were calculated using MATLAB (MathWorks, Natick, MA, USA) as follows (Winter,
200 2009):

$$201 \quad \omega_i = \frac{\theta_{i+1} - \theta_{i-1}}{2\Delta t} \text{ [deg/sec]}$$

202 where ω represents the angular velocity of the axial rotation of the pelvis and trunk, θ
203 represents the angle of axial rotation of the pelvis and trunk, i is the frame number, and Δt is
204 the time between adjacent frames (0.005 sec). In addition, the normalised angular velocity of
205 the pelvis and trunk were calculated relative to their peak angular velocities. The normalised
206 trunk rotation velocity at the time of peak pelvic rotation velocity was derived (Fig. 1).

207



208 **Figure 1.** Normalised trunk rotation velocity and the length of time during pitching.

209 (a) Normalised trunk rotation velocity at peak pelvic rotation velocity and (b) the length of time

210 from the peak pelvic rotation velocity to the peak trunk rotation velocity.

211 FC: foot contact; MER: maximum shoulder external rotation

212

213 The normalised trunk rotation velocity at the time of peak pelvic rotation velocity represents

214 the degree to which trunk rotation is suppressed when the pelvic rotation velocity reaches its

215 peak. Additionally, the length of time from the peak pelvic rotation velocity to the peak trunk

216 rotation velocity and the onset time of trunk rotation were also calculated to compare the

217 findings of this study with those of previous studies (Aguinaldo et al., 2007; Aguinaldo et al.,

218 2009; Graaff et al., 2018; Urbin et al., 2013). In addition, the onset time of trunk rotation was

219 calculated as the time from foot contact to the peak trunk rotation angle relative to the pelvis
220 in the pitching direction (Aguinaldo et al., 2007; Aguinaldo et al., 2009). The peak external
221 elbow valgus and shoulder external rotation torques were analysed during the arm-cocking
222 phase (Fleisig et al., 1995). The external elbow valgus and shoulder external rotation torques
223 were normalised by each participant's body height and mass (Derrick et al., 2020). The
224 average of the 3 pitches was used for data analysis (Post et al., 2015).

225

226 **Statistical Analysis**

227 IBM SPSS (version 22, IBM, Armonk, NY, USA) was used for the statistical analysis. The
228 Shapiro–Wilk test of normality was conducted to investigate the normality of the data. Since
229 normality was observed for all variables, Pearson's correlation analysis was used to
230 determine the correlations of the normalised trunk rotation velocity, the length of time from
231 the peak pelvic rotation velocity to the peak trunk rotation velocity and the onset time of
232 trunk rotation with ball velocity and the peak elbow valgus and shoulder external rotation
233 torques. Correlation coefficient thresholds of 0.1, 0.3, 0.5, 0.7, and 0.9 were interpreted as
234 small, moderate, large, very large, and extremely large, respectively (Hopkins et al., 2009).
235 The significance level was set to less than 5%.

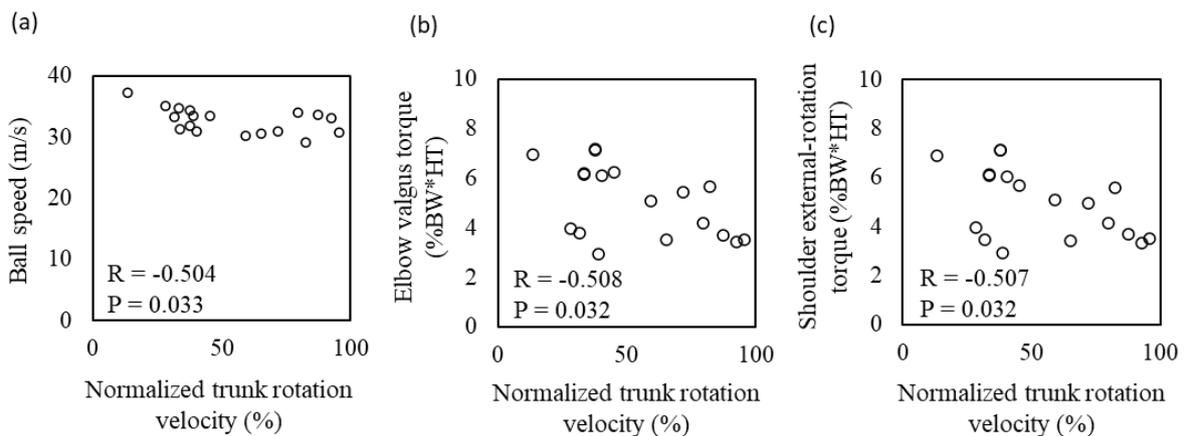
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237

238 **RESULTS**

239 The normalised trunk rotation velocity at the time of peak pelvic rotation velocity had a
240 significant negative correlation with ball speed ($R = -0.504$, $P = 0.033$, Fig. 2a), elbow valgus
241 torque ($R = -0.508$, $P = 0.032$, Fig. 2b), and shoulder external rotation torque ($R = -0.507$, $P =$
242 0.032 , Fig. 2c). These correlations indicate that a smaller normalised trunk rotation velocity
243 was associated with a faster ball speed and larger elbow valgus and shoulder external rotation
244 torques. A longer time from the peak pelvic rotation velocity to the peak trunk rotation velocity
245 was correlated with a faster ball speed ($R = 0.473$ $P = 0.047$, Fig. 3a) but was not correlated
246 with a higher elbow valgus or shoulder external rotation torque (Fig. 3b and c). The onset time
247 of trunk rotation had no significant correlation with ball speed or elbow valgus or shoulder
248 external rotation torque (Fig. 4).

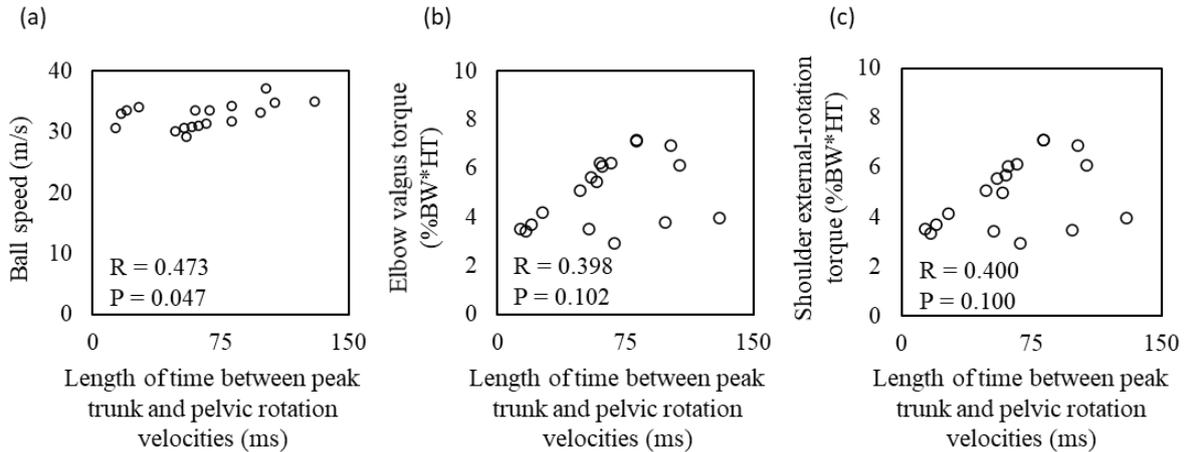
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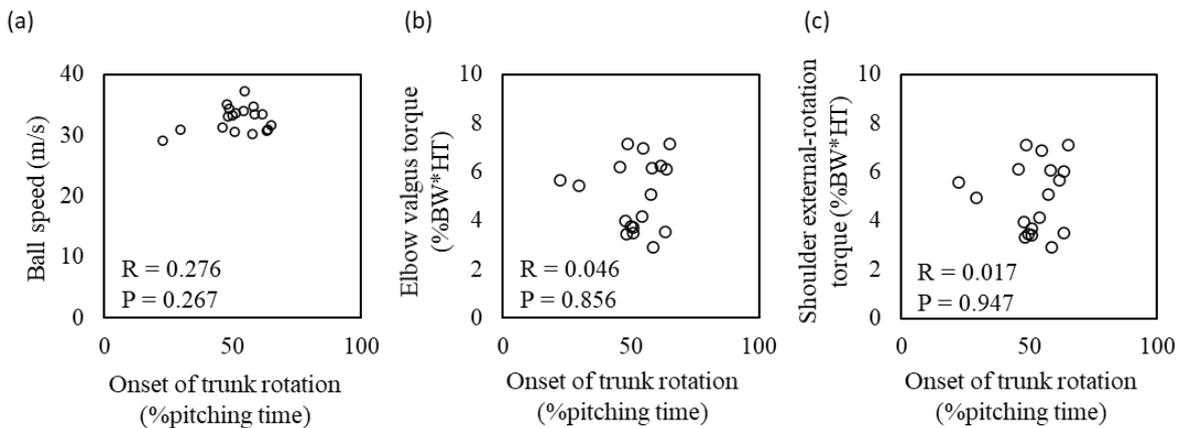
250 **Fig. 2** Correlation between the normalised trunk rotation velocity and (a) ball speed, (b) elbow
251 valgus torque, and (c) shoulder external rotation torque. The normalised trunk rotation velocity

252 had significant negative correlations with ball speed and elbow valgus and shoulder external
 253 rotation torques.

254



255 **Fig. 3** Correlation between the length of time between the peak trunk and pelvic rotation
 256 velocities and (a) ball speed, (b) elbow valgus torque, and (c) shoulder external rotation torque.
 257 The length of time between the peak trunk and pelvic rotation velocities had a significant
 258 positive correlation with the ball speed.



259 **Fig. 4** Correlation between the onset of trunk rotation and (a) ball speed, (b) elbow valgus
 260 torque, and (c) shoulder external rotation torque. The onset of trunk rotation had no significant

261 correlation with ball speed or elbow and shoulder external rotation torques.

262

263 **DISCUSSION AND IMPLICATIONS**

264 The results of the present study showed that a smaller normalised trunk rotation velocity at
265 peak pelvic rotation velocity was significantly associated with a faster ball speed, which
266 supported our hypothesis. However, in contrast to the hypothesis, a smaller normalised trunk
267 rotation velocity at the peak pelvic rotation velocity is associated with larger peak elbow
268 valgus and shoulder external rotation torques.

269 The present result indicates that suppressed trunk rotation during pelvic rotation
270 movement was associated with a faster ball speed. Although the peak trunk rotation angular
271 velocity was an important factor in achieving a faster ball speed (Bullock et al., 2020), the
272 suppression of trunk rotation during the arm cocking phase was also considered an important
273 factor in faster ball speed (Graaff et al., 2018; Sgroi et al., 2015). Suppressing trunk rotation
274 during pelvic rotation contributes to better transfer of momentum produced by the lower
275 limbs to the ball through the pelvis, trunk, and upper limbs in pitching (Sgroi et al., 2015).

276 The present study used the normalised trunk rotation angular velocity to evaluate the
277 suppression of trunk rotation because the peak magnitude of the trunk rotation angular
278 velocity may affect the absolute value of the trunk rotation angular velocity at the peak pelvic
279 rotation velocity. A pitcher with a larger peak trunk rotation angular velocity may have a large

280 absolute trunk rotation angular velocity even if the trunk rotation angular velocity was
281 suppressed relative to its peak magnitude. Therefore, the angular velocity of trunk rotation at
282 the peak pelvic rotation angular velocity was normalised by its peak magnitude. Moreover,
283 the correlation between the normalised trunk rotation angular velocity and ball speed found in
284 our study was large (Hopkins et al., 2009). Thus, the normalised trunk rotation velocity at
285 peak pelvic rotation velocity would be useful for objectively evaluating the suppression of the
286 trunk rotation velocity during the arm-cocking phase.

287 A smaller normalised trunk rotation velocity was significantly associated with
288 larger elbow valgus and shoulder external rotation torques. In a previous study, pitchers who
289 rotated their trunk before foot contact applied larger elbow valgus and shoulder internal
290 rotation torques than those who rotated their trunk after foot contact (Aguinaldo et al., 2007;
291 Aguinaldo et al., 2009). Based on these findings (Aguinaldo et al., 2007; Aguinaldo et al.,
292 2009), it was hypothesised that a high normalised angular velocity at the time of peak pelvic
293 rotation velocity, which is presumably linked to early trunk rotation, would be associated
294 with high elbow valgus and shoulder external rotation torques. However, the results were
295 contrary to the hypothesis and suggested that suppressing trunk rotation during pelvic rotation
296 could be associated with larger elbow valgus and shoulder external rotation torques. One
297 possible explanation for this discrepancy between the present and previous studies is that no
298 participants in the present study showed early trunk rotation before foot contact (i.e., negative

299 onset of trunk rotation). Suppressed trunk rotation during the arm cocking phase may not
300 decrease elbow and shoulder torques among pitchers who demonstrate trunk rotation after
301 foot contact. Otherwise, a faster ball speed may lead to lower elbow and shoulder torques
302 simply due to the smaller ball speed.

303 The length of time between the peak angular velocities of pelvic and trunk rotation
304 was also reported as the assessment of suppressed trunk rotation during the arm cocking
305 phase. The results of the present study showed a significant correlation between the length of
306 time and ball speed, which is consistent with a previous study (Graaff et al., 2018) but
307 inconsistent with another study (Urbin et al., 2012). The length of time would be affected by
308 the total pitching time. The time from the peak pelvic rotation velocity to the peak trunk
309 rotation velocity may be longer in slower pitching motion than in faster pitching motion.
310 Therefore, the length of time of the angular velocities of pelvic and trunk rotation may not
311 fully represent the suppression of trunk rotation during pelvic rotation. Thus, the normalised
312 trunk rotation angular velocity may be a good alternative to quantifying the timing of trunk
313 motion during pitching that accounts for the overall speed/length of the pitching motion.

314 Regarding clinical implications, the results of this study indicated that a smaller
315 normalised trunk rotation velocity was associated not only with a faster ball speed but also
316 with larger elbow valgus and shoulder external rotation torques. Larger external elbow valgus
317 and shoulder external rotation torques are considered risk factors for elbow and shoulder

318 injuries (Agresta et al., 2019; Anz et al., 2010; Sabick et al., 2004). Therefore, although an
319 emphasis on suppressed trunk rotation in the cocking phase may benefit in increasing ball
320 speed, the risk of elbow and shoulder injury should be acknowledged. Pitchers performing
321 pitching while suppressing trunk rotation require the strength of elbow varus and shoulder
322 internal rotation muscles to resist elbow valgus and shoulder external rotation torques during
323 pitching and stabilise each joint (Fleisig et al., 1995; Fleisig et al., 1996; Park et al., 2004;
324 Udall et al., 2009).

325 This study has some limitations. First, this study was cross-sectional. Therefore, the
326 cause-effect relationship of trunk rotation movement with ball speed and elbow valgus and
327 shoulder external rotation torques is unclear. In future studies, the effect of pelvic and trunk
328 rotation interventions on ball speed and elbow and shoulder loading and the relationship of
329 pelvic and trunk rotational velocities with the incidence rates of elbow or shoulder injuries
330 need to be investigated. Second, the present study examined pitching on a flat floor towards a
331 circular target. In an actual game, the pitcher wears spikes and throws from a mound into a
332 strike zone, a distance of 18.44 m. A previous study demonstrated that the timing of pitching
333 events in the pitching cycle and peak shoulder and elbow joint angular velocity and torques
334 were different between pitching from a mound and from flat ground (Nissen et al., 2013). In
335 addition, the reliability and measurement error of the normalised trunk rotation velocity have
336 not been established. Further studies are needed to investigate the reliability in a closer

337 situation to the actual outdoor pitching. Fourth, the sample size was generally considered
338 small for a correlational analysis, although this was determined by our pilot study. Fifth,
339 overhand throwing was determined by participants' self-reports and examiner's visual
340 assessments, and the arm slot was not calculated in the present study. Finally, we investigated
341 the correlation relationships without adjustment for *P* values, as in other similar studies
342 examining the association between trunk kinematics and pitching speed, elbow valgus torque
343 and shoulder external rotation torque (Aguinaldo et al., 2009; Leura et al., 2020). However,
344 the repeated tests increase the probability of a study-wise type I error.

345

346 **CONCLUSIONS**

347 The smaller normalised trunk rotation velocity at peak pelvic rotation velocity was associated
348 with larger elbow valgus and shoulder external rotation torques as well as a faster ball speed
349 in male pitchers playing on a competitive baseball team. The present findings suggest that
350 suppressing trunk rotation could increase the ball speed but may also increase elbow and
351 shoulder torques among pitchers who demonstrate trunk rotation after foot contact.

352 Assessment of normalised trunk rotation velocity may be a good way to quantify the timing
353 of trunk rotation that accounts for the overall length of the pitching motion.

354

355

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357 None.

358

359 **DISCLOSURE STATEMENT**

360 No potential conflicts of interest were reported by the authors.

361

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364

365

366

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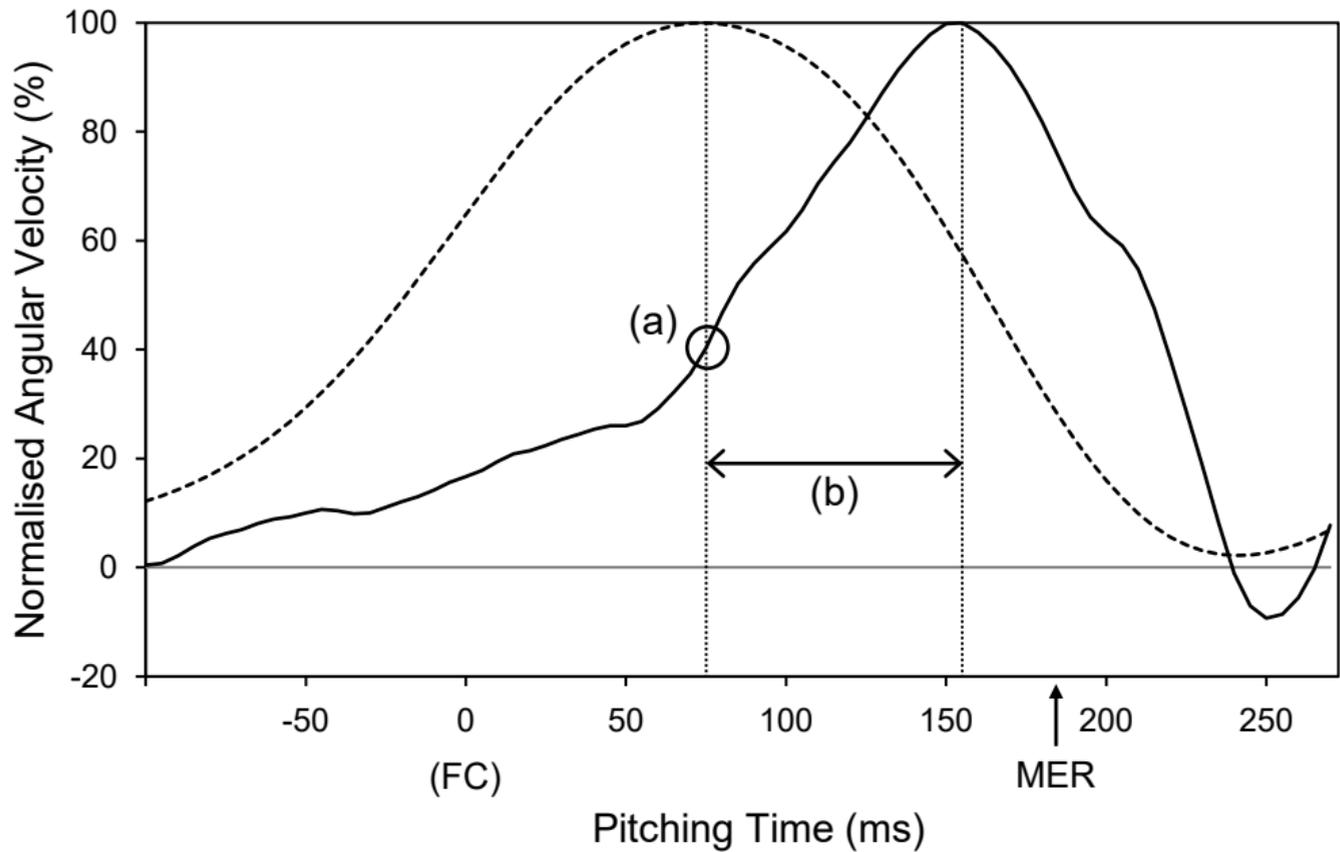
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501

502 **Table 1 Characteristics of participants (N = 18)**

Characteristic	Value
Age, years	21.7 (1.2)
Height, cm	174.7 (6.1)
Mass, kg	73.2 (7.7)
Pitcher experience, years	7.9 (3.5)
Throwing hand (right), N (%)	16 (89%)
Ball speed, m/s	32.7 (2.0)
Peak elbow valgus torque, %BW*HT	5.1 (1.4)
Peak shoulder external rotation torque, %BW*HT	5.0 (1.4)
Normalised trunk rotation velocity at the peak pelvic rotation velocity, % ^a	54.2 (24.7)
Length of time from the peak pelvic rotation velocity to the peak trunk rotation velocity, ms	63.8 (31.7)
Onset of trunk rotation, % ^b	51.8 (10.9)

503 ^aRelative to the peak trunk rotation velocity

504 ^bRelative to the pitching time



— Trunk Rotation

- - - - Pelvic Rotation

