

- 1 THE TRAINING EFFECTS OF WEARABLE RESISTANCE ON THROWING
- 2 PERFORMANCE IN COLLEGIATE BASEBALL PITCHERS: A PILOT STUDY

## 3 ABSTRACT

4  
5 *Purpose:* The objective of this study was to explore the effects of training using wearable  
6 resistance (WR) applied above the elbow of the throwing arm on throwing velocity, arm speed,  
7 shoulder internal (IR) and external rotation (ER) strength and range of motion (ROM), in baseball  
8 pitchers. *Methods:* College baseball pitchers (n=17) participated in a volume matched six-week  
9 throwing program, twice per week, unloaded (quasi-control) and with WR added to the upper arm  
10 (intervention). Arm speed was measured with an inertial sensor, throwing velocity via radar gun,  
11 shoulder rotator peak force (Fmax) with a strain gauge and ROM by a goniometer, pre and post  
12 training. Linear mixed effects models were used to examine differences between groups, time (pre  
13 and post) and their interaction, with random intercepts for participants. *Results:* A significant effect  
14 from pre- to post-testing was observed in ER ROM ( $\eta_p^2=.456$ ,  $p=.005$ ) and tended to increase  
15 more in the control group (interaction,  $\eta_p^2=.261$ ,  $p=.047$ ). Otherwise, no other statistically  
16 significant differences were observed. *Conclusion:* This was the first WR training study with  
17 pitchers and the lack of clear improvement using above arm WR loading was notable. Future  
18 researchers should explore the efficacy of lower arm loading and/or potentially increase training  
19 volume, as a means of stimulating adaptation.

20  
21 KEY WORDS: loaded throwing; shoulder strength; pitching; resistance training; throwing  
22 velocity  
23

## 24 INTRODUCTION

25 Throwing is a fundamental skill in baseball, with pitching being a specialized form of throwing.  
26 The speed at which a pitcher can throw is advantageous by decreasing a batter's time to recognize  
27 a pitch, making it a key goal for training programs at all competition levels <sup>1</sup>. Throwing is a total-  
28 body effort where energy is transmitted and sequentially increased from the lower-body through  
29 the shoulder <sup>2</sup>. Improving force production capability can enhance throwing performance <sup>3</sup>;  
30 however, since pitching relies on technical proficiency (e.g., throwing mechanics) and throwing  
31 arm injuries are common <sup>2,4-6</sup>, long-term success likely depends on balancing the development of  
32 physical and technical skills, and accordingly adopting appropriate training methods.

33  
34 All else being equal, increased throwing velocity (TV) requires greater neuromuscular demands—  
35 the product of the shoulder internal rotators (IR) accelerating and external rotators (ER)  
36 decelerating a faster arm <sup>2</sup>. There is evidence of a positive relationship between shoulder IR and  
37 ER peak force (Fmax) and TV ( $R^2 = 12\text{-}13\%$ ,  $p < .05$ ) <sup>7</sup>. With different throwing responsibilities,  
38 it seems logical to develop strength in both actions to contribute to and withstand the demands of  
39 throwing while reducing injury likelihood <sup>8-10</sup>. Various training methods exist to enhance TV, and  
40 can be divided into non-specific and specific training methods <sup>1</sup>, with the latter the focus of this  
41 article.

42  
43 Weighted balls have traditionally been used in specific training methods. Weighted balls (57-907-  
44 g) used over six to 15 weeks with youth, high school, and college baseball athletes have effectively  
45 increased TV 3.1-7.3% <sup>1</sup>. This specific method loads the throwing arm with the weighted ball in  
46 the hand, distal to the shoulder, overloading the arm accelerators. Typically, the throw becomes  
47 unloaded at ball release limiting overload of the arm decelerators. Weighted ball “holds” can  
48 overcome this limitation by retaining an overweight ball past the release point. Holds can  
49 effectively overload elbow flexion torque and the biceps as an elbow extension decelerator <sup>11</sup>,  
50 although potentially disrupting throwing mechanics. Moreover, some caution the use of weighted  
51 balls due to injury concerns and ER range of motion (ROM) increases <sup>12,13</sup>. Indeed, increases in  
52 shoulder ER ROM are linked with TV improvements <sup>14,15</sup>, but are also associated with increased  
53 medial elbow torque whilst throwing, which has been associated with injury <sup>6,14</sup>. Clarity is needed  
54 regarding necessary strength levels, ROM, and ball mass or throwing volume progression when  
55 applying weighted ball and adjacent techniques. Alternatively, securing loads along the throwing  
56 arm, otherwise known as wearable resistance (WR) could be implemented. Loads placed above or  
57 below the elbow, rather than the hand, could overload the throw following ball release without  
58 disruption of timing while throwing <sup>16</sup>.

59  
60 Securing WR to the throwing arm is relatively unexplored. Similar to throwing with a weighted  
61 ball, a primary rationale is an ability to integrate load at throwing-specific speeds e.g.,  
62 7,000<sup>o</sup>+/second <sup>17</sup>. Moreover, unlike weighted balls, since WR remains affixed to the arm, WR  
63 could overload arm accelerators and decelerators, before and after ball release, respectively <sup>16,18</sup>.  
64 Accordingly, the athlete can distribute WR in specific locations (i.e., above- or below-elbow),  
65 which could allow for targeted muscular overload. There is a paucity of research quantifying the  
66 effects of WR. Throwing with below-elbow loads (150-g and 200-g) acutely decreased arm speed  
67 (5.1-6.3%) and TV (100-200-g, 1.8-2.7%,  $p < .05$ ) <sup>16</sup>. Above-elbow loading, up to 200-g, did not  
68 significantly affect arm speed or TV, and loads could likely be increased due to the proximal load  
69 placement. Therefore, research is needed that quantifies greater above-elbow load effects and

70 whether throwing with WR can induce meaningful adaptations over a block of training<sup>19</sup>. Above-  
71 elbow WR could be strategic for baseball players where less rotational overload occurs, possibly  
72 target the shoulder musculature and minimize ER ROM increases. Practically, this approach would  
73 load the entire throwing motion, including post-ball release.

74  
75 Given the treatise of the literature, the aim of this study was to determine if a throwing program  
76 using WR applied above-elbow could improve shoulder rotator strength and TV in baseball  
77 pitchers compared to non-loaded throwing. We hypothesized that applying WR while throwing  
78 should increase both shoulder ER and IR Fmax and TV. Additionally, we hypothesised that no  
79 significant changes in ROM would be observed. Although the optimal prescription of training load  
80 and placement is unknown, this study should enhance our understanding of the utility of WR  
81 training for throwing performance.

## 82 83 METHODS

### 84 *Subjects*

85 Healthy, male collegiate baseball players (see Table 1) volunteered to participate in this study and  
86 provided written consent. While this was primarily a sample of convenience, the probable  
87 participant numbers were judged sufficient to detect medium-to-large effects with sufficient power  
88<sup>12</sup>. To be included in the analysis participants needed to attend 80% or more of the training sessions.  
89 Subsequently, two participants were removed from the intervention group (one attended 42% of  
90 sessions, and another sustained a non-related injury). In the control group, two participants missed  
91 the post-testing throwing assessment, but their data was retained for other analyses. In the final  
92 analyses, the control group included eight participants, and the intervention group included nine.  
93 This sample size left us somewhat underpowered compared to our original estimates. To achieve  
94 80% power with an alpha of .05 a partial eta squared ( $\eta_p^2$ ) of approximately .12—considered  
95 borderline 'large'—would be required; note this was based on an a simplified repeated-measures  
96 design (excluding random effects). We discuss the implications of this in the interpretations of our  
97 results. The study was approved by the institutional ethics committee (AUTEC 22/304).

98  
99 \*\*\*Insert Table 1\*\*\*

### 100 101 *Study Design*

102 Participants took part in a parallel-groups trial, where both groups performed the same volume of  
103 throws. The intervention group integrated above-elbow WR during 12 practices (twice weekly)  
104 over a six-week period, whereas the quasi-control group threw without WR (referred to as 'control'  
105 moving forward). Participants completed a pre- and post-training test battery, which quantified  
106 throwing performance, shoulder rotator strength and flexibility.

### 107 108 *Methodology*

#### 109 Initial processes: Familiarization

110 Participants completed a health questionnaire (PAR-Q+ 2022) prior to testing to determine  
111 possible risks of exercising based on health history and current symptoms. An explanation of the  
112 pre- and post-training procedures was presented as an information sheet and any questions  
113 regarding these procedures were answered. The familiarization session occurred two weeks prior  
114 to pre-testing and consisted of introducing the testing protocols and throwing with WR. While all

115 athletes and coaches were briefed on testing procedures and familiarized with the WR, they were  
116 blinded to the study's hypotheses.

117

118 Pre-testing (and post-testing): Specific procedures, group allocation

119 Pre-testing occurred one week prior to the start of the training study and post-testing occurred in  
120 week seven after the training intervention finished. Testing sessions occurred during mid-day at a  
121 convenient time chosen by the subjects. Pre- and post-testing took place over a two-day period.  
122 The first day included recording height, weight, passive shoulder ER and IR ROM and shoulder  
123 ER and IR Fmax. The second day included an assessment of unloaded throwing performance.  
124 Without resistance, TV was tested from the "stretch" position and was measured by radar gun  
125 (Stalker ATS II Version 5.0.2.1, Applied Concepts Inc., Richardson, TX, USA) mounted behind  
126 the target. Participants did not engage in upper-body resistance training 24-hours prior to testing.

127

128 Passive shoulder ER and IR ROM were measured via goniometer (Elite Medical Instruments,  
129 Orange County, California, USA). Participants were supine on a plinth with the shoulder placed  
130 at 90° of abduction and 10° of horizontal shoulder adduction, the scapula secured and the elbow at  
131 90° of flexion. Consistent positioning and measurement techniques were used across all  
132 participants and testing sessions. Two testers completed standardized passive ROM assessment  
133 training and were consistently used to minimize variability. Two trials were performed, one tester  
134 stabilized the scapula and placed the participant into position, and the other aligned and measured  
135 ROM with the goniometer [intra-rater intraclass correlation coefficient (ICC) = .62]<sup>20,21</sup>.

136

137 Shoulder rotator strength was measured as described previously<sup>22</sup>. Athletes performed maximum  
138 isometric contractions (see Figure 1) to measure throwing arm shoulder ER and IR strength  
139 [reliability estimates of coefficient of variation (CV) = 4.3-5.8%, ICC = .79-.85]<sup>22</sup>. Force-time  
140 data was collected at (1,000 Hz) using a custom, wireless strain gauge (Hawkin TruStrength,  
141 Portland, Maine). Once in position, participants were verbally instructed to start and complete the  
142 trial to capture Fmax – "push as hard and as fast as possible." Five trials for each action were  
143 performed, with three seconds per trial to minimize fatigue. Participants were given one-minute  
144 rest between trials.

145

146 \*\*\*Insert Figure 1 here\*\*\*

147 **Figure 1.** Strength assessment of Fmax during shoulder internal rotation (1A) and external rotation  
148 (1B) in the supine 90 testing position. The measurement device is visible positioned between the  
149 wrist and rack in each position.

150

151 On day two of testing, TV without load was measured to provide a practical measure of  
152 performance. Participants performed maximum effort throws into a target from 6.1 meters. Peak  
153 TV was measured via radar gun set directly behind the target. Additionally, an inertial  
154 measurement unit (IMU) (Figure 2A. PULSE Throw workload monitor, Driveline, Kent,  
155 Washington, USA) was worn on the throwing arm below the elbow of participants (attached via  
156 strap) for each throw. Arm speed was measured during testing and recorded for analysis (estimates  
157 of reliability from previous publications CV = 2.9-4.3%, ICC = .79-.86)<sup>23-25</sup>.

158

159 \*\*\*Insert Figure 2 here\*\*\*

160 **Figure 2.** Above-elbow arm sleeve featuring PULSE throw workload monitor (2A) and above-  
 161 elbow loading with 200-g (2B).

162

### 163 Training

164 Group allocation and adherence: Following pre-testing, athletes were randomly allocated to each  
 165 group, based on random number generation. Statistical difference between the allocated groups  
 166 was tested using independent t-tests for Fmax and TV following pre-testing. The remaining data  
 167 analysis was conducted following the intervention period. The primary researcher supervised  
 168 training during the study to account for attendance and adherence to proper arm loading protocols.

169

170 The training intervention occurred during baseball practice and required no additional time from  
 171 the participants. It consisted of two sessions per week over six-weeks, with a minimum of 48-  
 172 hours between loaded throwing sessions. During training, athletes performed three sets of five  
 173 throws with a standard baseball while securing WR to a Velcro sleeve (Lila Exogen Exoskeletons,  
 174 Sportboleh Sdh Bhd, Malaysia) on the throwing arm (see Figure 2B). Each session started with a  
 175 standardized dynamic warm-up followed by a self-selected number of unloaded throws prior to  
 176 applying WR. Load increased over the six-week intervention while volume (total throws) remained  
 177 constant (see Table 2). Subjects rested 30-seconds between throws and one-minute between sets.  
 178 After the throwing intervention, subjects continued with their coach-led baseball training. The  
 179 control group followed the same practice structure, including warm-up and throwing volume, but  
 180 did not use WR during any part of their training.

181

182 \*\*\*Insert Table 2\*\*\*

183

### 184 Data analysis

185 Key variables were TV, arm speed, and shoulder ER and IR Fmax and ROM. Arm speed and TV  
 186 were averaged from three trials. Shoulder rotator Fmax was averaged across five trials for ER and  
 187 IR, respectively. Shoulder ROM used the greatest measurement of two trials for each action  
 188 separately.

189

### 190 Statistical Analysis

191 Statistical analyses were performed using the R language and environment for statistical  
 192 computing<sup>26</sup>--specifically the *tidyverse*<sup>27</sup> environment for data treatment, the *lmerTest*<sup>28</sup> package  
 193 for models, *ggeffects*<sup>29</sup> to estimate marginal means, and various functions from the *easystats*<sup>30</sup>  
 194 framework (e.g., *performance* and *parameters* packages).

195 Descriptive statistics [mean  $\pm$  95% confidence intervals (CI)] were calculated for all dependent  
 196 variables extracted from pre- and post-training testing sessions. To address our primary aim and  
 197 assess the impact of training using WR (control versus intervention) and testing (pre- and post-  
 198 training) on throwing performance, strength, and ROM metrics, linear mixed-effects models were  
 199 used. This method was chosen due to its better handling of missing data and greater robustness to  
 200 certain assumption violations, which are discussed below. Models were fitted using restricted  
 201 maximum likelihood estimation, with *nloptwrap* optimization.

202 Distinct models were built with TV, arm speed and Fmax, and ROM for ER and IR as dependent  
 203 variables. Each model included group, time, and their interaction as fixed effects, with random  
 204 intercepts in the model for participants. Prior to interpreting these models, assumptions were fully

205 explored. Deviations from normal residuals (ROM Internal, Shapiro wilks,  $p = .007$ ) and  
206 differences in variance between the groups (TV and arm speed, Barlett test,  $p = .026-.041$ ) were  
207 observed, which were primarily attributed to a few outliers. We performed sensitivity analysis,  
208 and compared model fit and coefficients to those from robust models (using *rlmer* from *robustlmm*  
209 <sup>31</sup>). The impact of these violations was judged negligible (i.e., did not meaningfully change the  
210 results). We progressed with the original models, but this should be considered when interpreting  
211 the results. Marginal and conditional  $R^2$  values were reported as indices of model fit, and variance  
212 explained by the fixed effects and fixed plus random effects, respectively.

213 An analysis of variance was performed on each model, reporting the F statistic, p-values, and  $\eta_p^2$   
214 values as estimates of effect. The magnitude of the effect was interpreted using the following  
215 thresholds: very small ( $\eta_p^2 < .01$ ), small ( $\eta_p^2 = .01-.059$ ), medium ( $\eta_p^2 = .06-.13$ ) or large ( $\eta_p^2 >$   
216  $.14$ ).

217 In addition, the differences over time within each group were analyzed via pairwise contrasts on  
218 the estimated marginal means and expressed as mean differences in raw units alongside 95% CI  
219 and p-values. Particular attention to this analysis was placed when statistically significant  
220 interaction effects were observed. The significance level for all statistical tests was set at alpha =  
221  $.05$ .

## 222 RESULTS

224 Statistical models showed modest contributions from training group and time (marginal  $R^2 = .04-$   
225  $.29$ ), and greater variability explained by individual differences (conditional  $R^2 = .42-.76$ ).  
226 Relatively little variance was explained by IR Fmax (marginal  $R^2 = .08$ , conditional  $R^2 = .13$ ,  
227 respectively).

228 Key comparisons between WR and control groups are summarized in Table 3. No significant  
229 differences in arm speed or TV were observed over time or between groups. Changes in IR Fmax  
230 ( $\sim 17$  to  $19$  N) and ER Fmax ( $\sim 6$  to  $14$  N) were noted but were not significant. A significant  
231 interaction effect was observed only for ER ROM ( $\eta_p^2 = .261$ ,  $p = .047$ ), primarily driven by  
232 increases in the control group ( $+18.9^\circ$ ).

234 \*\*\*Insert Table 3\*\*\*

## 236 DISCUSSION

238 This was the first training study to investigate the effects of WR on throwing performance. It was  
239 thought that above-elbow WR loading may offer a training stimulus that could improve shoulder  
240 rotator strength and TV. After a six-week program the main findings were: 1) no significant  
241 changes in arm speed or TV were observed in the control or the WR groups; 2) rotator strength  
242 did tend to improve within the groups, albeit non-significant either for group, time or their  
243 interaction; and, 3) a significant within group change in the control ER ROM was noted.

244 The hypothesis that above-elbow WR would provide a sufficient training stimulus to increase arm  
245 speed and TV was not supported by our results. Somewhat surprisingly, no statistically significant  
246 changes were detected following training in either group. Nonetheless, some large effects were  
247 observed (e.g., in shoulder rotator strength,  $\eta_p^2 > .14$ ,  $p > .05$ ), which may be clarified with a larger  
248 cohort. Overall, the paucity of research investigating WR throwing makes comparing results  
249

250 problematic, however, researchers using weighted balls (113- to 170-g) have reported  
251 improvements (4.4-6.7%,  $p < .05$ ) in TV with greater throwing volumes (150-232 throws/week)  
252 over 10 weeks<sup>32,33</sup>. Another six-week study with similar throwing volume to this WR study (15-  
253 35 throws per week using weighted balls of 57- to 907-g reported a small increase (1%,  $p = .01$ )  
254 in TV with youth pitchers<sup>12</sup>. The increased velocity with the lesser throwing volume may be  
255 attributed to increased intensity from greater ball masses and the distal placement (i.e., in the hand),  
256 however, 24% of the weighted ball group dropped out due to injury<sup>12</sup>. Therefore, in future loaded  
257 throwing studies, load ad placement should be considered in overall intensity prescription. In the  
258 present study, one explanation is that the college pitchers in this study may have possessed an  
259 athletic background that required more individualized training, or higher volumes. Overall, it  
260 seems that the interaction between load placement and volume to produce training adaptation, is  
261 more complex than anticipated, particularly when considering better trained athletes. Further  
262 research is required.

263  
264 The proximal WR placement likely did not sufficiently increase rotational inertia to produce a  
265 training adaptation<sup>11,16</sup>. Considered alongside the weighed ball studies with greater rotational  
266 inertia (i.e., load more distal to the shoulder axis of rotation), the intensity of the overload and/or  
267 the volume in these studies could explain the unclear nature of TV increases<sup>12,32,33</sup>. Overall, the  
268 lack of clear group adaptation may have several explanations. The team's pre-determined training  
269 load from which the sample were recruited might have been insufficient to yield a training effect.  
270 It is possible that the WR load was insufficient in terms of placement and/or load, or volume (30  
271 throws/week) to differentiate the training stimulus between the two groups; however, further  
272 research is needed to determine the minimum effective dose for WR adaptations in throwing  
273 athletes. Additionally, results may have been smaller effects than expected, and increased power  
274 from more participants and measurement points may have clarified our interpretations.

275  
276 Strengthening the shoulder rotators is important to improve pitching performance and injury  
277 resilience<sup>7,9,10</sup>. Determining ways to increase shoulder rotator strength, while maintaining efficient  
278 throwing mechanics is essential to increase TV. It is difficult to conceive 100-400-g as adequate  
279 overload to increase shoulder strength, however, when light loads are moved quickly, they produce  
280 increased angular kinetic energy and resultant muscular work (i.e., work-energy relationship).  
281 Thus, it was hypothesized that a WR throwing program would increase shoulder rotator strength  
282 due to high velocity, sport-specific strength training. Although not statistically significant ( $p =$   
283  $.099$ ), we observed small improvements in ER Fmax with greater mean increases from the  
284 intervention group (+7.6% vs +3.1%, respectively). While unclear whether this result is  
285 meaningful, greater increases in ER strength with WR has a conceptual basis, attributed to loaded  
286 deceleration. Nonetheless, our hypothesis was unsupported, no changes in shoulder rotator Fmax  
287 were observed in either group following the intervention. Similar ambiguous results have been  
288 observed in the literature with a weighted ball training study with high school pitchers reporting  
289 no improvements in TV compared to a control group, despite increases in strength<sup>34</sup>. Therefore,  
290 the relationship between training, strength and TV can be complicated and needs more research to  
291 clarify the WR dose-response relationship.

292  
293 The only change detected between groups over time was a large increase in ER ROM ( $\eta_p^2 = .261$ ,  
294  $p = .047$ ), primarily attributed to ROM increases in the control group (+19°), seemingly somewhat  
295 counterintuitive. For example, increased layback during the arm cocking due to distally held

296 weighted balls might have increased ROM in a study which reported significant increases in ER  
297 ROM (+4.7%,  $p = .01$ ) compared to a control group ( $p = .02$ ) accompanied with increased TV <sup>12</sup>.  
298 In this study the non-significant effects associated with the WR group can likely be attributed to  
299 the proximal loading therefore having little effect on the layback and ER ROM <sup>12</sup>, however, further  
300 investigation is required. In our experiment, the mean value for pre-test ROM for those in the  
301 control group was lower ( $119.8^\circ$  vs  $138.8^\circ$ , respectively), which might explain some degree of  
302 adaptation in this group. No changes in IR ROM were observed, consistent with previous weighted  
303 ball research <sup>12</sup>. One unique aspect of WR is the ability to manipulate load placement. More distal  
304 load placement on the forearm would produce greater rotational inertia, and may have resulted in  
305 greater increases in ER ROM, similar but likely less than the weighted ball study <sup>12</sup>. Regardless, it  
306 does seem that above-elbow WR using similar loading to this study, can be integrated into training  
307 without increasing ER ROM. However, whether this holds in a more substantial sample, or when  
308 manipulating factors to increase training efficacy (e.g., increasing the load or position of loading)  
309 remains unknown.

310  
311 There are some limitations to consider regarding this study. Despite the a-priori information  
312 regarding the size effects we might observe, ultimately the study was likely underpowered  
313 following subject loss. Thus, a larger sample might have clarified potentially interesting  
314 differences between the cohorts and over time, which we were unable to detect. Future studies  
315 might opt to collect data from a larger cohort, albeit at the risk of decreased standardization via  
316 recruitment from likely different teams (and surrounding activities). Similarly, it is possible that  
317 training adaptations had not yet been realized <sup>35</sup>, and having a second post-testing session could  
318 have allowed for longer recovery and supercompensation. Additional post-testing occurrences  
319 were considered, but unfortunately untenable due to team scheduling. Future researchers should  
320 consider multiple assessment time-points where possible, and multiple post-test occasions to  
321 bolster the understanding of potential adaptations and identify a minimum effective WR dose.  
322 Finally, this study used absolute loads throughout the intervention and future WR prescriptions  
323 could consider body mass relativity.

324

## 325 PRACTICAL APPLICATIONS

326 Training with WR, as prescribed in this study, may not be sufficient for increasing TV or shoulder  
327 strength in well-trained athletes. Coaches should consider increasing loaded throwing session  
328 volume, load, frequency or duration to elicit a training effect. Furthermore, applying loads below-  
329 elbow should be considered to provide substantial overload. As the first WR throwing-specific  
330 training study, above-elbow placement was selected to maintain velocity and minimize joint  
331 loading (i.e., excluding elbow and wrist). Low throwing volume was selected with the athletes'  
332 safety in mind, particularly due to injury concerns with weighted ball training <sup>12,13</sup>; however,  
333 volume with above-elbow loading might be increased to elucidate WR effects. Given that proximal  
334 loading may have minimal impact on ER ROM, WR potentially offers a safer option to increase  
335 training intensity without exacerbating injury risks associated with increased ROM.

336

## 337 CONCLUSION

338 Applying above-elbow WR over a six-week, twice per week throwing program was ineffective in  
339 improving TV and shoulder rotator strength in collegiate baseball pitchers. Nonetheless, our  
340 findings provide important guidelines for future research regarding how this method might be

341 better adapted, notably regarding magnitude of overload and volume of the dose-response  
342 relationship.

343

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