Tremonia
Fechterkurier

Concerning the Reliability of the Waggle Test

Dynamic parameters define a rigid body's reaction to external forces. While their importance for a sword's behaviour is known since the 19th century [1–3], many data sets of original swords, replicas and training weapons include mass and the centre of mass, but lack a third parameter such as moment of inertia, radius of gyration, or corresponding centres of oscillation/percussion. A third parameter, however, is required to calculate a rigid object's response. Several setups for the measurement of the moment of inertia have been commercially available for decades; but among HEMA practitioners and sword researchers, the most widespread method for the assessment of a third parameter is the so-called *waggle test* [5, 6] which was introduced in a point-up variant in the early 21st century [7], and is now more commonly used point-down [8]. The waggle test gives the position of the centre of oscillation corresponding to any given axis, which might explain why many attempts to interpret the dynamic properties of a sword focus on the positions of centres of oscillation.

NB: Among today's swordsmen, the term *centre of percussion* is often used to denote a *node of vibration* instead of a *centre of oscillation*. Learn more about this confusion in [4].

Le Chevalier explained the proper execution of the waggle test. [8] He also examined the effect of the imposed oscillation period on the precision of the test. In this article, overall precision and trueness of the waggle test will be assessed on the basis of experimental data.

1 Setup and Methods

For the experiment, two wooden broomsticks were sawed to cylinders with the length $l = 1.216\,\mathrm{m}$, radius $r = 0.0122\,\mathrm{m}$ and mass $m = 418\,\mathrm{g}$. The calculated first principal moment of inertia is thus $I_{\mathrm{calc}} = 51.5\,\mathrm{g\,m^2}$. The participants of the experiment were instructed to mark the centre of mass using a rubber band, mark the point at which they wanted to hold the stick and then find and mark the corresponding centre of oscillation following the instructions given in Le Chevalier's introduction to the waggle test [8]. Additionally, they were instructed to turn the broomstick upside down, repeat the waggle test using the found centre of oscillation and check if they would now find the original point as the corresponding centre of oscillation. The product of the broomstick's mass and the distances of the corresponding centres of oscillation from the centre of mass is the moment of inertia about the centre of mass. For each measurement it should be equivalent to the calculated one.

One part of the experiment was conducted at the DDHF[1]-Trainertage, an educational event for HEMA trainers, where eight data sets were obtained. The second part was conducted at the club Tremonia Fechten. The participants were beginners, experienced practitioners and one of the trainers. This part provided seven data sets.

Additionally, five data sets of swords and rapiers from the 16th and 17th century were obtained from the GEEhW[2], which analyses period swords, in particular the swords' morphological properties. These data sets include mass, the position of the centre of mass and two pairs of corresponding centres of oscillation measured with the waggle test. [9] The moment of inertia is thus overdetermined. While we cannot calculate the swords' true moments of inertia, we can compare the results from each of the pairs of corresponding centres of oscillation in order to determine the precision of the measurements.

2 Results and Discussion

The broomstick experiment gives an arithmetic mean of the measured principal moment of inertia $\bar{I} = 33.6\,\mathrm{g\,m^2}$ with the standard deviation $\sigma = 13.1\,\mathrm{g\,m^2}$. The coefficient of variation is thus $\sigma/\bar{I} = 39.0\,\%$ and the relative bias is $(I_{\mathrm{calc}} - \bar{I})/I_{\mathrm{calc}} = 34.8\,\%$. See Fig. 1 for a graphic representation. The results from the trainers group (DDHF, measurements 1 through 8) are similar in terms

[1] Deutscher Dachverband Historischer Fechter (German HEMA umbrella organisation).

[2] Gesellschaft zur Erforschung und Erprobung historischer Waffen (Society for Studying and Testing Historical Weapons).

of trueness and precision to those of the mixed group (Tremonia Fechten, measurements 9 through 15).

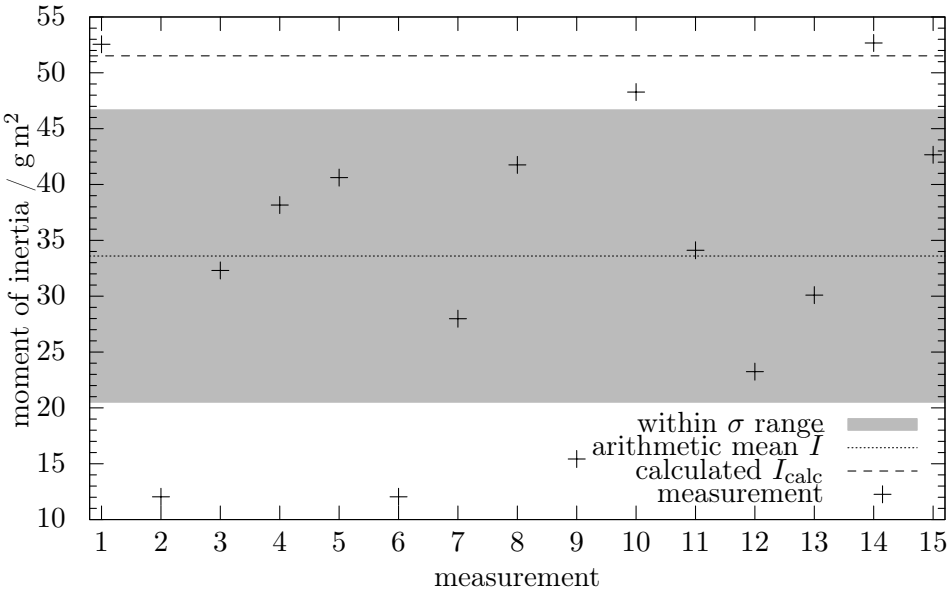

Figure 1: Measured moments of inertia (crosses) with their arithmetic mean (dotted line) and standard deviation (grey area) in comparison with the calculated moment of inertia (dashed line).

The GEEhW guidelines suggest measuring the centres of oscillation corresponding to both ends of the sword grip, so we can calculate the moment of inertia about the centre of mass from each centre of oscillation. As the moment of inertia about a given axis does not change in a rigid body, the difference between the results indicates the precision of the waggle test. The results are shown in Fig. 2. The calculated moments of inertia differ from their respective arithmetic means by 56 % to 95 %, the mean relative difference is 73 %.

Typical simple measurements of distances involve errors in the low percent range. Most kitchen scales work within even lower error margins. So, the limiting factor for an accurate determination of the dynamic parameters of swords is the waggle test.

In two separate experiments, participants with fairly accurate measurements were told that their data was incorrect, and they were asked to reproduce results

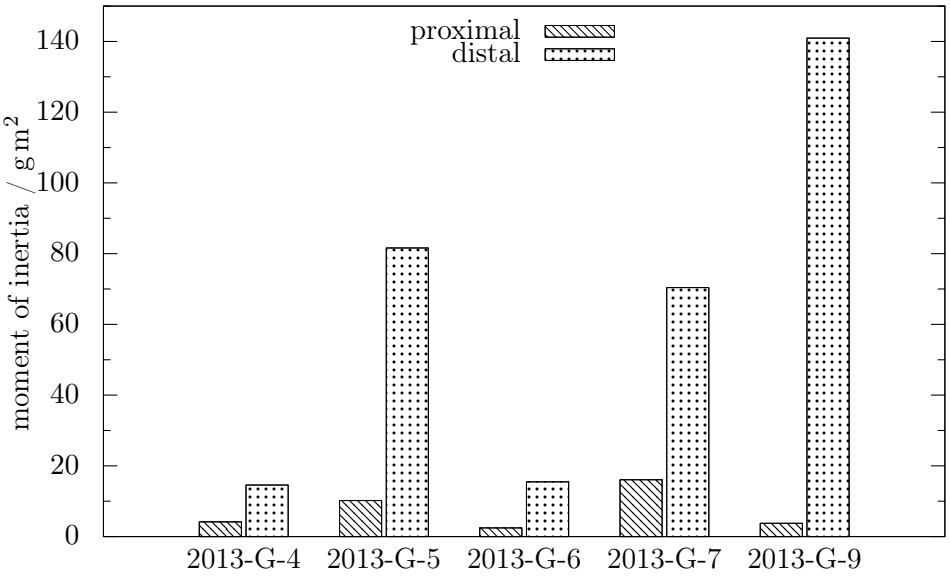

Figure 2: Moments of inertia calculated from corresponding centres of oscillation; 'proximal' refers to the corresponding centres of oscillation closer to the pommel, 'distal' closer to the point.

which were described as being exact, but actually were farther off than their own respective measurements. In both cases, the participants were able to reproduce the given wrong values as correct. If this susceptibility to suggestion is a common effect, particular caution should be exercised if measurements were made with an expectation in mind, e.g., that a specific type of sword is supposed to have a certain position of a centre of oscillation.

3 Conclusion and Outlook

While we do see some waggle test results which are fairly close to the calculated moment of inertia, the overall data indicate that results from waggle tests should be taken with caution. This observation is supported by the degree of mismatch between the moments of inertia from different pairs of corresponding centres of oscillation that could be found in waggle test data from period swords and rapiers. It is therefore suggested to replace the waggle test with a more accurate method.

I am currently collaborating with constructor, HEMA practitioner and blade-smith Patrick Schröter on a rigid gravity pendulum for measuring the moment of inertia of swords with sufficient accuracy. The device will be simple to use. First measurements with a preliminary setup have a relative bias of 4 % and a relative standard deviation of 4 %.

4 Acknowledgement

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