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*SHORT AND SWEET*

# Galileo's dagger

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**Abstract.** Galileo found that fine lines on a balance scale dazzled his eyes and were unreadable. So he used a grid of fine wires instead and ran his dagger across it, counting the number of auditory clicks. This is the first known experiment on sensory substitution.

**Keywords:** Galileo, acuity, sensory substitution

Galileo Galilei (1564–1642) was probably the very first person to examine the psychophysics of numerosity, and he did so as a side issue from his main purpose in a short treatise that he wrote in 1586 at the age of 22, entitled *La Bilancetta* [The little balance]. In this treatise he expressed doubts about Vitruvius's description of how Archimedes, crying "Eureka!", unmasked the fraud in Hiero's crown; and he presented his own method, using a beam balance.

In what follows, all the quotations are in Galileo's own words (translated into English in Fermi & Bernardini's, 1961, book).

> "Let us suppose, for instance, that a gold ball is immersed in water. If the ball were made of water it would have no weight at all because water inside water neither rises nor sinks. … Because metals are of different [specific] gravity, their weight in water will decrease in different proportions. [If] gold weighs twenty times as much as water, [then] gold will weigh less in water than in air by a twentieth of its total weight [in air]. Let us now suppose that silver, which is less heavy than gold, weighs twelve times as much as water; if silver is weighed in water its weight will decrease by a twelfth. Thus the weight of gold in water decreases less than that of silver, since the first decreases by a twentieth, the second by a twelfth."

Galileo proposed making a beam balance, with a gold ball hanging at one end and a counterpoise at the other. The position of the counterpoise along the arm of the balance was adjusted until it balanced the gold ball (in air). If the gold ball were now immersed in water, its weight would decrease by a twentieth and the counterpoise would have to move one twentieth of the distance toward the fulcrum to rebalance. For silver, the counterpoise would have to move one twelfth of the way. Galileo argued that he could compute the ratio of gold to silver in an alloy crown, by weighing it first in air and then in water, and noting how far along the arm he had to move the counterpoise.

The problem now was to measure the position of the counterpoise very accurately. It would be difficult in the 16th century to file a series of accurately spaced detents along the bar to constrain the position of the counterpoise. Galileo solved this problem by tightly winding a very fine wire along the bar. The spacing between the detents would now be equal to the diameter of the wire, which would provide very fine gradations. But now arose a visual problem in reading the scale. In Galileo's words:

> "Here we must warn that a difficulty in counting arises: Since the wires are very fine, as is needed for precision, it is not possible to count them visually, because the eye is dazzled by such small spaces."

The tightly wound wire was like a high-spatial-frequency grating, where the bars of the grating—the wires—were easy to resolve but very hard to count. This would be true not only if they were viewed for a brief subitising flash but also if they were slowly inspected given ample time. It seems difficult to fixate each bar in turn, and to keep track of which bar is which, since they are all indistinguishably alike. Galileo had a beautifully simple solution to this problem:

> "To count them easily, therefore, take a most sharp stiletto and pass it slowly over the said wires. Thus, partly through our hearing, and partly through our hand feeling an obstacle at each turn of wire, we shall easily count said turns."

So Galileo came up with a nonvisual solution to the visual problem, by converting a hard-to-resolve spatial array into a series of auditory clicks that were easy to count over time.

Other researchers have tackled problems in one sense modality by looking for solutions in another modality. For instance, Paul Bach-y-Rita (Bach-y-Rita, 2004; Bach-y-Rita, Collins, Saunders, White, & Scadden, 1969) invented an admirable series of video devices that converted a picture into a spatial array of tactile vibrators, which gave the blind a form of vision. So he is often credited with inventing sensory substitution. But Galileo got there first.

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