JAMES McKEEN CATTELL AND THE METHOD OF CONSTANT STIMULI IN THE PSYCHOPHYSICS OF MOVEMENT

Roger Adams[1], Kwee-Yum Lee[2], Gordon Waddington[3] and Hae-Jung Lee[4]
[1]University of Sydney, [2]Australian Catholic University, [3]University of Canberra, [4]Silla University
Faculty of Health Sciences, University of Sydney, Australia
<roger.adams@sydney.edu.au>

Abstract

In 1892, Cattell & Fullerton published a paper on "The Psychophysics of Movement" in which they summarised their findings from the application of Fechner's methods to the study of the extent, force, and time of arm movements made without the aid of vision. Using a form of Munsterberg's apparatus (Titchener, 1905) they found the method of right and wrong cases to be 'the most accurate of the methods' and the difference associated with 75% correct judgement to be the 'most convenient measure of discrimination'. By 1990s, however a major work on examining the role of proprioception in joint stability listed only the methods of adjustment (Joint Position Sense) and limits (Kinesthesia) as being ways of measuring movement sensitivity. Recent technical developments have enabled researchers to employ the Cattell & Fullerton method to obtain psychophysical measures of proprioception derived from the comparison of active movements made to physical stops.

The first experiments on the psychophysics of active movement were conducted by Fechner (1860) with judgments of the amount of force required from the upper limb for it to overcome the resistance due to gravity for a specific weight. The judgments were then used to derive a measure of sensitivity. The experimental method employed by Peirce and Jastrow in 1884 involved judgment of the finger force needed to counter an upwards pressure on beam of a post-office scale from a weight placed in the pan, but it was not until the work of Fullerton & Cattell (1892) that the first judgments were made of differences in the extents of active movements made to physical stops.

Methods of Constant Stimuli, Adjustment, and Limits in the Psychophysics of Movement

The use of comparison of the extent of movements made to physical stops, without the aid of vision, as an experimental method for research into the psychophysics of movement seems to have been jointly developed by James McKeen Cattell and Hugo Munsterberg, who had been classmates in Wundt's Psychophysical Seminar series in Leipzig in the summer of 1885 (Blumenthal, 1997). Munsterberg later supervised the dissertation of Edmund Burke Delabarre, presented in Freiburg in 1891, in which an apparatus he devised (Figure.1) for assessing both horizontal and vertical arm movements was used (Worringham, 1992). Edward Titchener (1905) lists his Fig. 30 as 'Munsterberg's apparatus' and notes that the car, which travels on three horizontal tracks, has a vertically-set brass cylinder for the subject's forefinger, and 'two sliding blocks, which can be set at any point along the middle track, to mark the beginning and end of the two movements' (p.104).

In contrast, the apparatus used by Fullerton and Cattell (Figure 2) had a horizontal brass ring between the front and back wheels of the carriage, into which the seated subject inserted their finger to make a movement. The carriage ran in grooves cut into a brass plate fixed to a tabletop, and metal pins could be inserted to define the extents of movements. A screen obscured vision.

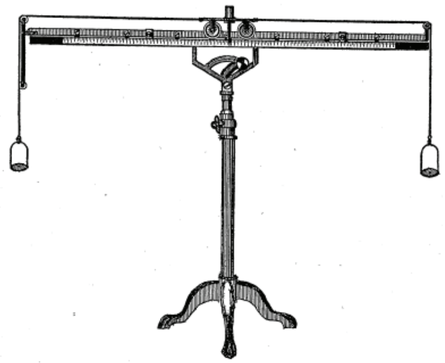

FIG. 30.

Figure 1. Munsterberg's apparatus for the comparison of movements of the arm. From Titchener (1905).

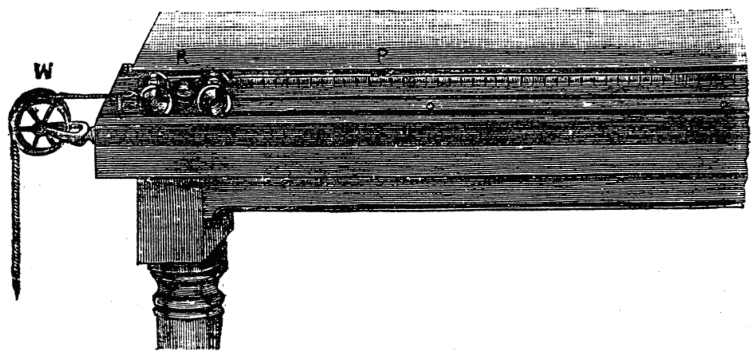

FIG. 2.—APPARATUS FOR MEASURING THE EXTENT OF MOVEMENT.

Figure 2. Apparatus for measuring discrimination of the extent of arm movements. From Fullerton & Cattell (1892).

The adjustable stops for limiting movement of the trolley and defining the beginning and end of arm movements, S' and S'' can be seen more clearly in the apparatus used by Charles Myers (1911) at Cambridge University (Figure 3).

Cattell's first doctoral student at Columbia University, Robert Sessions Woodworth, later supervised the dissertation of Harry Hollingworth, who substituted wood-fiber wheels in place of the original metal ones, to 'more completely eliminate the noise made by the moving carriage' (Hollingworth, 1909, p.7). However, Hollingworth only used the Adjustment Method (Average Error) in his studies, and titled his dissertation 'The Inaccuracy of Movement'. His somewhat pessimistic conclusion to his work was that 'great uncertainty arises in the application of the psychophysical methods to the study of movements' (p.82). Hollingworth's research marked the end of the early study of movement psychophysics.

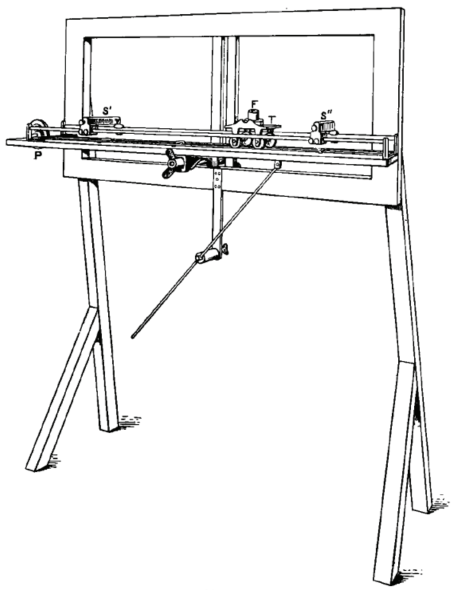

Fig. 5.

Figure 3. Apparatus for studying the limen of just-perceptible active movement. From Myers (1911).

Plate II

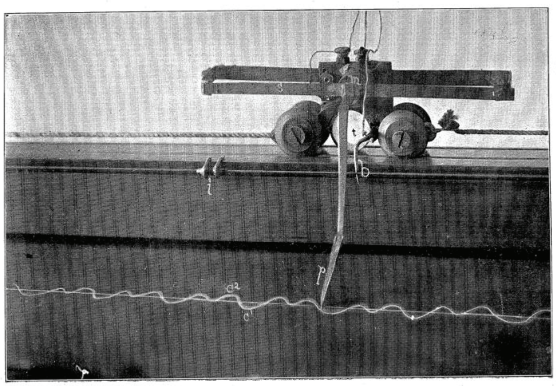

Figure 4. Movable carriage for studying arm movement. From Hollingworth (1909).

The Use of Stopped Movements in Movement Psychophysics

Fullerton & Cattell (1892) noted that it is only in the method of right and wrong cases (later constant stimuli) that both movements ‘are determined by two uprights’, whereas in the adjustment methods the movable upright at the end of the movement is sometimes removed. The inference here is that tasks asking subjects to compare different kinds of movements will involve cognitive processes not usually associated with everyday movement control. Indeed, Laszlo (1992) has argued that when the first (or criterion) movement is made to a stop, and the subsequent reproduction movement is ended in space by the subject, without a stop, then the assumption that the two movements rely on the same sensory-motor processes is not a valid one.

Early in the twentieth century, research into the psychophysics of movement had become directed towards questions associated with simultaneously controlling or manipulating the duration, force and extent of movements, the psychophysical method that was to be used, the time order error, and whether subjects should be permitted to use 'equal' or 'doubtful' judgments. Others, however, saw the discrimination sensitivity index as a useful measure, separate from the question of psychophysical scaling.

The Einstellung Psychophysical Judgment Process for Movement

Georg Elias Muller, the German researcher to whom Fechner gave his set of weights, proposed a different basis for comparison underlying psychophysical judgment than Fechner. Whereas Fechner argued that in the method of right and wrong cases each lifted weight was compared with a memory reference value that was the average of the two weights (Link, 1992), Muller in 1889 proposed the 'Einstellung' hypothesis. By this account, on the second lift, the subject unconsciously sets the same motor command parameters that had previously been successful in overcoming the downwards force on the first lift (Boring, 1929). If the result was that the arm moved up more quickly, the second weight was judged lighter, and if more slowly, judged heavier. Applied to stopped movements, this account would suggest that subjects, while attempting to move at a constant pace, generate an expected stop position, and if the movement continues past this, it is judged longer than on the previous trial, and if stopped before it, judged shorter.

Muller was visited in Gottingen by Charles Spearman, who subsequently argued that the most promising application of the psychophysical measure of sensitivity was to be found in describing individual differences in ability and distinguishing between conditions which either enhanced or worsened the ability to discriminate (Spearman, 1908).

Obtaining an index of discrimination sensitivity to compare conditions of testing under experimental manipulation, in the manner suggested by Spearman, however, must address the difficulties clearly outlined by Cattell and Fullerton (1892) when they summarized the work of Fullerton and Cattell (1892). Here they noted that the method of right and wrong cases was the most accurate of Fechner's methods for studying the psychophysics of movement, but that it required a considerable number of trials and "is consequently not well suited for provisional, anthropometric, or clinical purposes" (p.447). As a measure, they suggested that "the probable error, that is the difference with which an observer is right 75% of the time, is the most convenient measure of discrimination", calculated using the probability integral.

Psychophysical Measures in Proprioception Testing and Joint Injury Assessment

A domain with an obvious need for accurate and valid assessment of sensitivity is the clinical musculoskeletal domain, especially with respect to assessment of athletes following joint injury. It was therefore possibly the time cost of obtaining probable error estimates that meant that 100 years later, only two methods of obtaining a measure of sensitivity were listed for testing joint proprioception (Lephart, Riemann, & Fu, 2000), these being versions of the Method of Average Error (Adjustment) and the Method of Limits, and listed as Joint Position Sense testing, and Kinesthesia testing, respectively.

Because the ankle is the most frequently injured joint in the body (Witchalls et al., 2012), an accurate measure of movement discrimination at the joint is needed for assessing the extent of injury to an athlete and for success of rehabilitation (Figure 5). Cattell's method of using comparison of active movements made to physical stops without the aid of vision therefore needs to be adapted to testing movements in lower limb rather than upper limb joints, and needs to be made more efficient to reduce the time demand of testing.

Three developments have enabled this. The first was the development of the Method of Single Stimuli (Woodworth & Schlosberg, 1966) which halves the number of trials by removing the standard stimulus. The subject must use a memory representation of the stimulus values to make judgments. The second development was non-parametric signal detection analysis via ROC curves (Swets, 1988) which permits the calculation of a bounded discrimination index, the AUC (Area Under the Curve). Finally, the availability of computer-controlled stepper motors, used to accurately position read heads on hard drives and control spot welding in auto manufacturing, has provided a laboratory system for resetting physical stops that is fast, error-free, and able to replicate stop settings to tolerances of 1/100 of a millimeter.

Figure 5. Active Movement Extent Discrimination Apparatus (AMEDA) for testing sensitivity to differences in extent for ankle plantarflexion and inversion movements. The physical stop blocks labeled 'D', 'M' and 'S' set the Deep, Mid, and Shallow distances down from horizontal, at 14, 11 and 8 degrees respectively. The aluminum plates, in a row at the front of the apparatus, provide a set of depths to discriminate for each block.

With these developments, it has become possible to continue the psychophysical research on stopped movements that Cattell started 120 years ago. Discrimination measures obtained using various versions of the AMEDA (Active Movement Extent Discrimination Apparatus) have been used to quantify the followings: the value of balance board rehabilitation (Waddington et al., 1999); the effects of textured athletic shoe insoles (Waddington & Adams, 2003); the risk of poor hip movement discrimination score for subsequent hamstring injury (Cameron et al., 2003); the role of vision in judging neck movements (Lee et al., 2004); and the effects of retraining on movement discrimination after anterior shoulder dislocation (Naughton et al., 2005). The research sequence involves identifying the action of interest, then designing a system for stopping a set of different movement extents that can then be used to generate a score representing a person's ability to differentiate extents on the dimension of interest. As there are almost an infinite number of combinations of actions of interest in different individual/contexts, this method seems to have a potential to become one of most promising applications in psychophysics as Spearman foresaw.

References

Boring, E.G. (1929). *A history of experimental psychology*. New York: Appleton Century Crofts.

Blumenthal, A.L. (1997). Wilhelm Wundt. In W.G. Bringmann, H.E. Luck, R. Miller & C.E. Early (Eds.), *A pictorial history of psychology*. Chicago: Quintessence Publishing Co.; pp. 117-125.

Cameron M., Adams, R., & Maher, C. (2003). Motor control and strength as predictors of hamstring injury in elite players of Australian football. *Physical Therapy in Sport*, *4*, 159-166.

Cattell, J.M., & Fullerton, G.S. (1992). The psychophysics of movement. *Mind*, New Series No.3, 447-452.

Fechner, G.T. (1966). *Elements of psychophysics* (Vol. 1) (E.G. Boring & D.H. Howes. Eds.; H.E. Adler, Trans.). New York: Holt, Rinehart & Winston. (Originally published 1860).

Fullerton, G.S., & Cattell, J.M. (1892). *On the perception of small differences: with special reference to the extent, force and time of movement.* Philadelphia: Uni. of Pennsylvania Press.

Hollingworth, H.L. (1909). The inaccuracy of movement. *Archives of Psychology*, *13*, 1-87.

Laszlo, J.I. (1992). Motor control and learning: How far do the experimental tasks restrict our theoretical insight? In J.J. Summers (ed.) *Approaches to the study of motor control and learning*. North-Holland: Elsevier Science Publishers, pp. 47-79.

Lee, H., Nicholson, L.L., & Adams, R.D. (2004). Sensitivity to differences in the extent of neck-retraction and -rotation movements made with and without vision. *Perceptual and Motor Skills*, *98*, 1081-1089.

Lephart, S.M., Riemann, B.L., & Fu, F.H. (2000). Introduction to the sensorimotor system. In S.M. Lephart & F.H. Fu (Eds.), *Proprioception and neuromuscular control in joint stability*. Champaign, IL: Human Kinetics.

Link, S.W. (1992). *The wave theory of difference and similarity*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Myers, C.L. (1911). *A text-book of experimental psychology with laboratory exercises.* Cambridge: Cambridge University Press.

Naughton, J., Adams, R., & Maher, C. (2005). Upper-body wobbleboard training effects on the post-dislocation shoulder. *Physical Therapy in Sport*, *6*, 1-7.

Peirce, C., & Jastrow, J. (1885). On small differences of sensation. *Proceedings of National Academy of Science, 3*, 75-83.

Spearman, C. (1908). The method of 'right and wrong cases' (constant stimuli) without Gauss's formulae. *British Journal of Psychology, 2*, 227-242.

Swets, J.A. (1988). Measuring the accuracy of diagnostic systems. *Science, 240*, 1285-1293.

Titchener, E.B. (1905). *Experimental psychology*. (Vol. II, Part I). New York: Macmillan.

Waddington, G., Adams, R., & Jones, A. (1999). Wobble board (ankle disc) training effects on the discrimination of inversion movements. *Australian Journal of Physiotherapy*, *45*, 95-101.

Waddington, G., & Adams, R. (2003). Football boot insoles and sensitivity to ankle inversion movement extent. *British Journal of Sports Medicine*, *37*, 170-175.

Witchalls, J., Waddington G., Blanch P., & Adams, R. (2012). Ankle instability effects on joint position sense when stepping across the Active Movement Extent Discrimination Apparatus. *Journal of Athletic Training*, in press.

Worringham, C.J. (1992). Some historical roots of phenomena and methods in motor behavior research. In G.E. Stelmach & J.Requin (Eds.), *Tutorials in motor behavior II*. North-Holland Amsterdam: Elsevier Science Publishers.