EUROPEAN YEARBOOK OF THE
HISTORY OF PSYCHOLOGY
SOURCES, THEORIES, AND MODELS

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CONTENTS

ORIGINAL ESSAYS

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CAN MENTAL FATIGUE BE MEASURED BY WEBER'S COMPASS?

ALFRED BINET'S ANSWER ON THE VALUE OF AESTHESIOMETRY (TACTILE SENSITIVITY) AS AN OBJECTIVE MEASURE OF MENTAL FATIGUE

Abstract

In 1834, the German physiologist Ernst Heinrich Weber (1795–1878) measured for the first time the tactile discrimination threshold with a compass. This paper describes an application of this technique to measure mental fatigue on students by Hermann Adolf Griesbach (1854–1941) and Alfred Binet (1857–1911). The former was the first to suggest, in 1895, the use of this technique, and Binet and his collaborator Victor Henri (1872–1940) published in 1898 the first monograph on mental fatigue, in which they devoted a chapter to the innovative work by Griesbach. The analysis of this book's content shows the origins of Binet's interest in aesthesiometry as related to mental fatigue. The second part of this paper examines Binet's work using aesthesiometry as an objective measure of mental fatigue.

Keywords

Aesthesiometry, Weber, Binet, Griesbach.

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Let us not forget that, when measuring tactile sensitivity, we are doing psychology.
Binet, 1903a, p. 128

One of the earliest psychological measurements that interested the nascent field of experimental psychology was devised by the German physiologist Ernst Heinrich Weber (1795–1878).

> The various parts of the touch-organ are not equally sensitive to the spatial separation of two simultaneous points of contact [of a compass]. The sensitivity can be measured by determining the distance between the two points; for it is a property of the touch-organ that it can always distinguish between two points set sufficiently far apart, even if it cannot distinguish between them when too close together (Weber, 1834, p. 47; English translation by H. E. Ross, cf. Weber, 1978).

This distance was called the tactile discrimination threshold or Weber's threshold. All students in physiology and psychology are familiar with the value of Weber's work: he was the first to calculate the tactile discrimination threshold, which is known to vary depending on different environmental, physical and mental factors. The corresponding literature, which will not be presented in this paper, has grown considerably over the last two centuries in the fields of physiology and psychology. Its application in the fields of health, work and education is less well-known, however. We will focus on the latter domain because it was investigated by one of the major figures of French psychology, Alfred Binet (1857–1911). Psychologists of the time carefully investigated the use of this technique as they wished to create an objective criterion to measure mental fatigue in young people.

The question of mental fatigue was not new (cf. Andrieu, 2004), as it arose with the establishment of compulsory schooling. The passing of Jules Ferry's laws in the early 1880s led to vast surveys and debate about schoolchildren's physical and mental health. During the period of 1880–85, the issue of mental fatigue came to embody the opposition between physicians and educators. The alarm was first sounded by the scientific and literary press, supported in 1886–87 by physicians who agreed on the importance of this topic. Gustave Lagneau (1886) submitted this question to the Academy of Medicine of Paris on 27 April 1886. Indeed, the consequences of mental fatigue were, for schoolchildren, both pedagogical and physiological (Riant, 1889). The debate ended after the sessions from the 17 May to the 9 August 1887 (cf. *Bulletin de l'Académie de Médecine*, volume XVII, p. 531; p. 673; p. 695; vol. XVIII, p. 11; p. 83; p. 143; p. 184; p. 221). Among the conclusions sent to the minister of public education featured the following points (cf. *Discussion sur le surmenage intellectuel et la sédentarité dans les écoles, séance du 9 août 1887*, in *Bulletin de l'Académie de Médecine*, 51e année, 1887, 2e série, vol. *18*, p. 240): 1° The need to increase the sleep time of young children; 2° The need, for all schoolchildren, to decrease the time devoted to study; 3° The need for all students to undertake daily physical exercise. But these conclusions were only the result of discussion and were not based on scientific investigations. How could mental fatigue be measured? At that time, experimental psychology was starting to provide some answers (e.g. Arai, 1912; Binet & Henri, 1898; Joteyko, 1898, 1904; Offner, 1911; Phillips, 1920), by conducting innovative studies within laboratories and schools, investigating the effect of physical and mental work on the body and the mind.

Several years later, Alfred Binet addressed the members of the Free Society for the study of Child Psychology in the following terms:

> You all know that, this summer [1904], an important conference on hygiene in schools took place in Nuremberg. There, German physiologists showed a curious procedure to measure mental fatigue in school children: the use of a compass to measure tactile sensitivity. It seems that when someone is in a state of mental fatigue, this sensitivity decreases, and that this decrease is measurable. This is very interesting but it is not new for psychologists […]. This issue is of critical interest for pedagogy, and we should therefore engage in further study. (Binet, 1904, p. 552).

Binet had been interested in aesthesiometry and in its application to mental fatigue for several years (e.g. Binet, 1880, 1886). In 1898 he co-authored a synthesis, the first of its kind, on mental fatigue (Binet & Henri, 1898). The detailed analysis of this work will reveal the origin of Binet's interest in mental fatigue and aesthesiometry. In the second part of the article, we will investigate this work using aesthesiometry as a tool for measuring mental fatigue.

1. *The first reference book:* La fatigue intellectuelle *(Binet & Henri, 1898)*

Fig. 1.
Cover of the original edition of Binet & Henri (1898) on mental fatigue.

The book by Alfred Binet and his student Victor Henri (1872–1940; Nicolas, 1994b) was published in the *Bibliothèque de pédagogie et de psychologie* edited by Schleicher (see Nicolas, 2015). *La fatigue intellectuelle* was the first volume[1] of this

[1] The second volume was supposed to be written by Binet's collaborator Victor Henri, on 'memory education'. But the book remained unfinished.

collection (Figure 1) directed by Binet.[2] Binet wanted to replace the old pedagogy by a new one, based on the recent developments of experimental psychology. Along with his collaborator, the aim of this book was (see also Jastrow, 1898): 1° to present the various experimental methods that were used to measure mental fatigue; 2° to study the effect of mental fatigue on various physiological functions (e.g. blood flow, breathing, nutrition); 3° to study the psychological consequences of intellectual work; 4° to describe the techniques used to measure mental fatigue; 5° to criticize the results already obtained and to underline the origin of potential errors. In particular, they sought methods that could be applied to groups of children in their classroom, and not within a lab. Their goal was practical: to give teaching and education a solid experimental background, and to clarify the approximate notion of 'mental fatigue'. First, the authors strongly criticized previous work done by French, German, English and American physicians. Then, they inserted in the book several dissertations that had been already published in Binet's journal, founded in 1895: l'*Année Psychologique* (Nicolas, Segui & Ferrand, 2000a, 2000b). The book by Binet & Henri (1898) is divided in two parts: the first and longest part concerns *the physiological effects of intellectual work* (pp. 33–224). The second part of the book is about *the psychological effects of intellectual work* (pp. 225–336).

1.1. The physiological effects of intellectual work

In the first part of their book (pp. 33–224), Binet and Henri (1898) showed that modifications occurred in the most vital physiological functions under the influence of intellectual work. For example, intellectual work had an effect on the heart beat rate as measured by Marey's transmission sphygmograph

[2] The *Bibliothèque de pédagogie et de psychologie* included the following volumes before its demise:
Binet, A., & Henri, V. (1898). *La fatigue intellectuelle*. Paris: Schleicher.
Sanford, E. T. (1900). *Cours de psychologie expérimentale.* Paris: Schleicher.
Binet, A. (1900b). *La suggestibilité*. Paris: Schleicher.
Bourdon, B. (1902). *La perception visuelle de l'espace*. Paris: Schleicher.
Binet, A. (1903b). *L'étude expérimentale de l'intelligence*. Paris: Schleicher.

(Figure 2). Original studies done by the authors, and published in the *L'Année Psychologique* by Binet and Courtier (1896, 1897a, 1897b, 1897c, 1897d), are presented in their book but also other work published by several scientists in foreign journals.

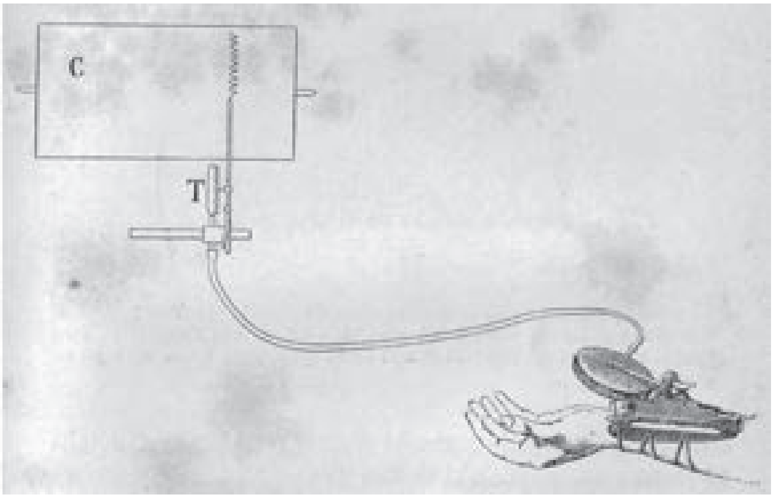

Fig. 2.
Marey's transmission sphygmograph. This device measures heart beat and produces a graphical representation. At T we find a rod, one of whose extremities is pressed against the artery, while the other extremity is connected to the rubber membrane of Marey's drum. This rubber drum connects the sphygmograph to the writing drum at T. A quill connected to the rubber membrane of the writing drum at T writes on the rotating cylinder (C) (Binet & Henri, 1898, p. 46).

Intellectual work could also have an effect on capillary circulation in the hand, as shown by Hallion and Comte's (1894) plethysmograph (Figure 3). But the experimental investigations carried out by Binet and Courtier (1896, 1897c), presented in the book, suggested that '*the observations related to capillary circulation are still too sparse to know what pedagogic applications they could have*' (p. 98).

Using a slightly modified version of Mosso's (1895) sphygmomanometer (Figure 4), Binet and Vaschide (1897) showed that intellectual work also had an effect on blood pressure: they found that complicated calculus increased the pressure of 20 ml of mercury. However, they concluded that '*one should study prolonged intellectual work to see if mental fatigue does indeed have an effect on blood pressure.*' (p. 127)

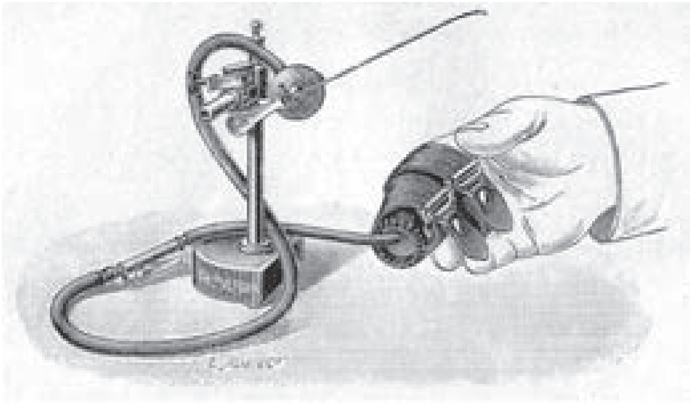

Fig. 3.
Hallion and Comte's Plethysmograph (Verdin, 1903).

Fig. 4.
Mosso's sphygmomanometer (Verdin, 1895, p. 95; 1903, p. 12). For a technical description see Binet and Vaschide (1897, pp. 128–29).

During intellectual work, the breathing rate as measured by Marey's or Laborde's pneumograph increased and became more superficial: the shortening concerned all phases of breathing, but was particularly marked during inspiration and pausing.

The amount of carbonic acid increased, and the authors underlined this phenomenon and its implications for the circulation of air in classrooms.

The authors also mentioned that no extensive work had been done on the effect of intellectual work on muscular strength. They examined this using an ordinary dynamometer (Figure 5) or Mosso's ergograph (Figure 6), modified following Binet's advice (cf. Binet & Henri, 1898, pp. 179–80). '*In summary, intellectual work seems to modify muscular strength; moreover, this modification differs depending on whether the work is short or sustained, and whether it is linked with a particular emotional state or not*' (pp. 195–96). Sustained intellectual work, as shown

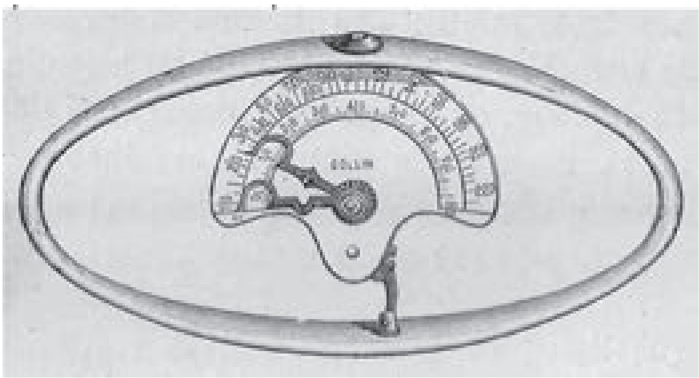

Fig. 5.
Collin's dynamometer commonly used to measure the strength of the flexor hand muscles (Binet & Henri, 1898).

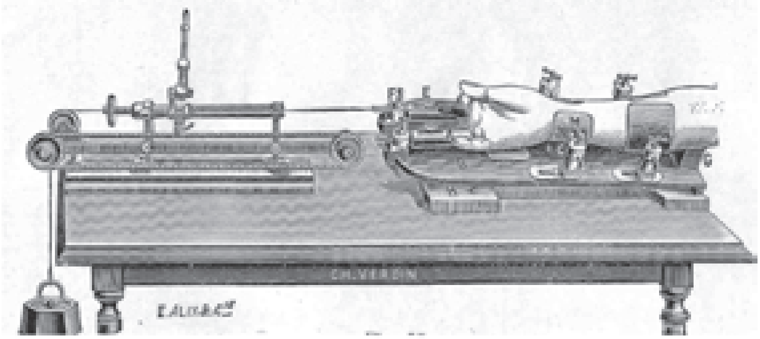

Fig. 6.
Mosso's ergograph presented by Charles Verdin (1890).

by Mosso's studies (1890, p. 153), seemed to be related to a considerable reduction in muscular strength.

In summary, intellectual work had a significant effect on important physiological functions, such as blood flow, breathing and muscular strength. Some of these modifications occurred after a brief period of intellectual work, while others were only observed during sustained and intense intellectual work. Finally, the authors stressed that '*no intellectual work can be done without effects on the organism; the duration and intensity of these effects being related to the type of intellectual work and the type of physiological function*' (p. 328). It seemed that for several physiological functions, a short duration of intellectual work produced modifications of one kind, and that sustained intellectual work produced modifications of the opposite kind. For example, the heart beat increased after a brief period of intellectual work and decreased during sustained intellectual work; the shape of the heart beat response was accentuated for a brief span of mental activity, but dicrotism decreased during sustained work; the blood vessels of the hand were constricted in the beginning of intellectual work but then vasodilation followed; the breathing rate also increased at the beginning, followed by a decrease. Finally, muscular strength seemed to be increased after brief intellectual activity, and weakened after a one-hour stint of intellectual work.

1.2. Psychological Effects of Intellectual Work

The second part of the book (pp. 225–336), shorter but just as dense as the first, focuses on the psychological effects of intellectual activity. It is mainly a more extended version of a literature review done by Henri (1897) on mental and physical work.

> Everybody knows that mental activity decreases after sustained mental work; one cannot focus one's attention, one becomes easily distracted, cannot remember what one is reading or hearing, makes mistakes when writing or doing calculus, and finally has more difficulties making associations, one no longer knows how to write a composition or solve a problem. These are the psychological effects that everyone has observed on himself (Binet & Henri, 1898, p. 225).

The authors showed that laboratory studies on this question can be divided in two groups. 1° We choose a certain type of intellectual work, make a participant do it for a sufficient duration (one day for example), and we see if the quality of the work changes during this lapse of time. This kind of research focuses on the effect of intellectual work on the work itself. 2° We choose a certain type of intellectual work, make a participant do it for a sufficient duration, and then study its effect on different mental functions (the memory of numbers, variations in the threshold of tactile sensitivity, duration of reaction times, etc.). Although many of these experimental studies had been done in Germany in Emil Kraepelin's laboratory (1856–1926) in Heidelberg (cf. Amberg, 1896; Bettmann, 1895; Oehrn, 1895; Rivers & Kraepelin, 1896), two other series of research investigations were also reported by the authors: those of the psychologist Hermann Ebbinghaus (1850–1909) and of the physiologist Hermann Adolf Griesbach (1854–1941).

Binet and Henri (1898) also detailed a recent study by Ebbinghaus (1896) on his experiments done in schools using calculus, memory for numbers and completion. They mention that at the end of the nineteenth century, German schoolchildren had

Fig. 7.
Portrait of Hermann Adolf Griesbach (1854–1941).

5 hours of class from 8 am to 1 pm, with only one 15 min break. However, only older students had 2 hours of class in the afternoon, while the younger pupils were free. In July 1895 the chief magistrate of the city of Breslau sent a letter to the Society for Hygiene, addressing the potential problem that this sustained work might raise regarding children's health. This letter followed many petitions made by parents complaining about nervous hyperexcitability and mental fatigue. The commission of teachers set up to examine this question requested the participation of Hermann Ebbinghaus (1850–1909, see Nicolas, 1994a), who had been recently appointed to the university of Breslau. The commission was rapidly convinced of the need to approach the problem experimentally, directly in schools. Mental fatigue was studied using three procedures: calculus, memory for numbers and completion. 1) *Calculus*. This procedure was already used by several authors (Bürgerstein, 1891; Laser, 1894; Holmes, 1895; Richter, 1895). For 10 minutes, the participant had to do additions and multiplications as quickly as possible, without making any mistakes. The number of correct operations was counted as well as the number of errors. However, as an error at one step could have repercussions on subsequent steps, only the original error was scored. 2) *Memory for numbers*. This procedure consisted in reading a string of six to ten digits and asking the participant to write it down in the same order (digit span procedure). 3) *Completion (Combination).* This procedure was brand-new. Ebbinghaus inquired about the main feature of an act of intelligence, and how to distinguish an intelligent man from a less intelligent one. He suggested that in order to be a good physician, it was not sufficient to have comprehensive knowledge and a good memory. One must also be able to make a correct diagnosis from a number of symptoms by combining, relating and synthesising different elements in order to extract a new meaning. Thus for Ebbinghaus the act of combination was the core feature of intelligence. But how could this ability be studied? The procedure was the following one: to remove some words and syllables from a text to obtain a text with gaps. Participants had to fill in the blanks as quickly as possible based on the context and the meaning of the surrounding sentences. Binet and Henri were highly critical of this research (a shortened version in French

was edited by the *Revue Scientifique*, cf. Ebbinghaus, 1897), but underlined their interest in the procedure of combination. '*In summary, Ebbinghaus' procedure must be studied even closer; it is indeed possible that it could generate some important practical results*' (p. 319). Several years later Binet and Simon (1905) used this procedure in their original metric scale (cf. Nicolas, Andrieu, Croizet, Sanitioso & Burman, 2013). Binet and Henri (1898) concluded this section of the book by presenting the *tactile sensitivity* method, recently used by the German physiologist Hermann Adolf Griesbach (1854–1941) (Figure 7) to measure mental fatigue. In order to measure differences in tactile sensitivity, physiologists and psychologists used Weber's compass (Figure 8), with the following procedure. If both points of the compass are applied simultaneously to the skin of a participant without him seeing, the participant will feel either one point, or both, depending on the distance between the two points and the sensitivity of the tactile region. When the two points of the compass are too close to each other, the person reports feeling a single point. There is a limit beyond which one can feel both points called the threshold of the sense of position. Binet and Henri (1898) presented a brief summary of Griesbach's (1895a, 1895b) experiments about how the strength of attentional focus differed after classes, based on the fact that a diminished strength of attentional focus was related to an increase in the threshold of the sense of position. He conducted experiments on high school and elementary school students, as well as on teachers and mechanics apprentices. Measurements of tactile sensitivity were made before and after each class, and after several hours of break and on Sunday at midday. Griesbach (1895a, 1895b) chose six locations on the skin: the forehead, nose, lower lip, cheekbone, thumb and index finger. The results spoke for themselves: tactile sensitivity diminished after intellectual work, for each of the six skin locations. The effect was greater for the least sensitive regions, where the threshold is the highest. Two hours of break reduced the value of the threshold to the baseline and, on Sunday, the threshold was lower than on school days. Experiments made before exams showed a substantial increase in the threshold; even after a five-hour break, the threshold was still above the baseline. Also, experiments made on mechanics apprentices showed that the variation in tactile sensitivity was only slight after physical work. Binet and Henri (1898) noted that these results were confirmed by Vannod (1896) and concluded that: '*We see that the procedure of measuring the threshold of the sense of position is useful for measuring mental fatigue in students.*' (p. 324).

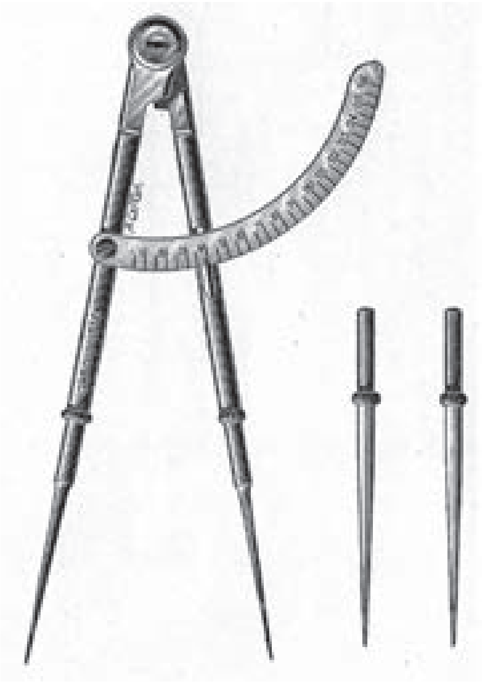

Fig. 8.
Weber's aesthesiometer (or Weber's compass), showing the distance between the points. The steel points were removable and could be replaced with ivory points. (cf. Boulitte, 1913, p. 367).

In the conclusion to their book (pp. 325–36) Binet and Henri (1898) compared different psychological procedures used to study fatigue. They noted that laboratory experiments on adults showed that after one hour of calculus, several elementary psychological effects started to appear. The reaction time increased; the participant read more slowly than before the intellectual work, he could not do additions as fast as before and his memory for numbers was also diminished. The value of these studies was not to show that fatigue increases with the duration and intensity of the intellectual activity, which is obvious, but to propose practical procedures able to demonstrate this fatigue objectively, even though it was not consciously perceived by the participant. After describing these procedures, such as dictation, calculus, number memory, method of combination and tactile sensitivity, Binet and Henri (1898) concluded as follows: '*We conclude our book by hoping that the French administration, which is too enlightened not to understand the interest of these studies, will be persuaded that no teaching issue will be solved by discussion, talk, and oratorical jousting. We trust that it will support, with all its might, experimental psychological research in schools.*' (p. 336). Although the procedure of dictation (cf. Sikorsky, 1879; Höpfner, 1894; Friedrich, 1897) was the one favored by the authors (as it easily measured a slackening of attention), they suggest in their conclusion that the use of tactile sensitivity could also be interesting.

2. *Griesbach and Binet's studies on mental fatigue measured by aesthesiometry*

Despite their interest in tactile sensitivity, Binet and Henri (1898) suggested that the relationship between the level of fatigue and the value of the threshold was not proportional. They considered that the procedure was unreliable in certain respects, and that it should not be used alone. Binet returned several years later to the use of this method to measure mental fatigue in a controversial context that developed around this question.

2.1. Hermann Griesbach: mental fatigue measured by tactile sensitivity.

As we have seen in the presentation of the content of Binet and Henri's book (1898), Griesbach (1895a, 1895b) was the first to have the idea of showing that mental fatigue could produce a temporary decrease in tactile sensitivity, measurable by Weber's compass. In a long article published in *Archiv für Hygiene*, he presented the summary of his work on aesthesiometry. He conducted these experiments mostly on College students in Mulhouse, in Alsace (a region belonging to Germany after the

French defeat in 1870–71), to see if the strength of attentional focus varied after classes, as this variation was related to an increase in the level of the tactile sensitivity threshold. 80 participants were studied. In children, measurements were made at the beginning and at the end of each class on the forehead, nose, lower lip, cheekbone, thumb and index finger. Tables 1, 2 and 3 show several typical cases.

Table 1: Aesthesiometric measurements of a 12-year-old healthy, hardworking student of average intelligence (C. F.) in the general studies section (Griesbach, 1895a, p. 145).

	7 to 8 Natural sciences		8 to 9 Maths	9 to 10 Geography	10 to 11 Sport	11 to 12 Break	14 to 15 Maths		___	Sunday
Time	7 am	8 am	9 am	10 am	11 am		2 pm	3 pm	4 pm	12 am
Forehead	3.5	4	10	9	9.5		4.5	11	11	3.5
Nose	2	2	2.5	3	3		1.5	3	3	2
Lower Lip	2	2	2.5	3.5	2		2	3	2	1.5
Cheekbone	4	5	9	15	13		6	14	14	3.5
Thumb	4	4	6	10	6		4.5	7	7	4
Index	1.5	1.5	2	3	2		1.5	2	2	1

Table 2: Aesthesiometric measurements of a 16-year-old student in the general studies section (Griesbach, 1895a, p. 175)

	7 to 8 Maths		8 to 9 Latin	9 to 10 Greek	10 to 11 Religion	11 to 12 Physics	12 to 14 Break	___	Sunday
Time	7 am	8 am	9 am	10 am	11 am	12 am		2 pm	12 am
Forehead	11	12	14	17	11	15		7.5	3.5
Nose	3	3.5	5	5	4	5		2.5	1.5
Lower Lip	2	3	3.2	4	3	3.5		1.8	1
Cheekbone	11	17	22	23	15	22		10	5
Thumb	6	10	13.5	13.5	9	11		5	4
Index	2.2	2.5	2.5	2.5	2	2.5		1.2	1

Table 3: Aesthesiometric measurements of a 17-year-old student (E. W.) in the industrial section. In this case the fatigue is very clear, and the example very typical (Griesbach, 1895a, p. 181)

PROGRAM	7 to 8 Mechanics		8 to 9 Mechanics	9 to 10 French	10 to 11 Maths	11 to 12 Geometry	___	Sunday
Time	7 am	8 am	9 am	10 am	11 am		3 pm	4 pm
Forehead	4.5	5.5	11.2	9	10.5	12.5	5	4
Nose	2.5	3	3.2	3	4	6.5	2	2
Lower Lip	3	3	4	3	3.5	4	2	1.5
Cheekbone	7.5	11	17.2	12.5	18	20	5.5	4.5
Thumb	4	6.5	6.5	7	–	9	5.5	3
Index	2.0	2.2	2.2	2.2	2.5	3	1.5	1.5

For each of these cases, the results were clear and suggested that the ability to discriminate decreases with fatigue. The distance between the two legs of the compass had to be increased for the participant to feel two distinct sensations. For example, if the minimum distance was 7 millimeters when not tired, this distance, in a participant affected by mental fatigue, would be 17 millimeters. TABLE 4 shows variations in the threshold during the morning and after certain classes. Griesbach's results showed that the threshold increased even more when the intellectual activity had been intense (cf. Vannod, 1896).

Table 4: Threshold value measured by Weber's compass during the morning in German students (Griesbach, 1895a; Henri, 1896)

TIME	AFTER CLASS	THRESHOLD
7 am	(before class)	7 mm
8 am	History	12.5 mm
9 am	Greek	17 mm
10 am	Bible Study	9 mm
11 am	Latin	14 mm
12 am	French	17 mm
2 pm	(after a 2-hour break)	10.5 mm

Finally, Griesbach (1895a) concluded that: 1° the level of fatigue was usually higher in high school than in secondary school. The adolescents did not sleep enough as school began too early. He recommended that school should start at 8 or even 9 am for the younger pupils. The midday break of 2 or 3 hours was not sufficient to recover from the fatigue accumulated during the morning. Moreover, digestion was not over at 2 pm and starting work could produce long term negative effects. 2° Griesbach recommended abolishing afternoon classes and replacing them with outdoor physical exercise. He believed that children should study in the morning and be free of intellectual work in the afternoon. 3° Final examinations should be abolished, at least in younger children, for they had negative consequences on physical and mental health. Oral examinations were more tiring than written examinations. Table 5 contains the results from aesthesiometry during finals in a student with good mental and physical health (finals took place during 4 days from 7 to 12 am).

Table 5: Aesthesiometric measurements during a series of written examinations of a 17-year-old healthy and intelligent student (P. D.) (Griesbach, 1895a, p. 193)

	1st day German composition		2nd day French		3rd day Maths		4th day English		Free day
Time	11.30 am	4.30 pm	10 am	1 pm	12 am	5 pm	10.30 am	1.30 pm	
Forehead	12	5	12	7	14	7.5	14	9	4
Nose	5	2	5	3	6	3.5	7	5	1.5
Lower Lip	3	1	3	2	3.5	2	3.5	2	1
Cheekbone	14	6	16.5	26	17	9	18.5	9	14.5
Thumb	8	5	9.5	5	10.5	5	10.5	6	4
Index	3	1.5	2.5	1.5	2.5	2	3	2.5	1

The fatigue associated with an oral examination is very well summarized in table 6 below:

Table 6: Aesthesiometric measurements before and after final oral examinations (the column 'another day' is the control condition) (see Abelson, 1908, p. 363)

	Before	After	Another day
Forehead	6	17	4
Nose	4	5	2
Lower Lip	2	3.5	1
Cheekbone	15	27	7
Thumb	6	10	4.5
Index	2	3.5	1

Weber, along with other authors using aesthesiometry, used an ordinary compass, with blunted points,[3] and manually applied this compass to the skin, varying the distance between the points. However, as this rudimentary compass presented several flaws (settings, application angle, unequal pressure,[4] simultaneousness of application), more precise compasses were developed, such as the compass with a slide[5] (Figure 9), or the dynamometric (Figure 10) compass.

[3] Binet (1903a, p. 104) wrote: 'As to the shape of the points, I will make a remark: if we blunt them, their shape will be less well defined, and the surface of contact will vary depending on whether the point is more or less pressed into the tegument.'

[4] Binet's collaborator, Victor Henri, used the simple compass a lot. He solved the problem of pressure by not holding the compass firmly in his hand but simply letting it rest on the skin with its own weight (cf. Binet, 1903a, p. 105).

[5] According to Binet (1903a, p. 104): 'The sliding compass is preferable to the ordinary one: the sliding compass is composed of two parallel points,

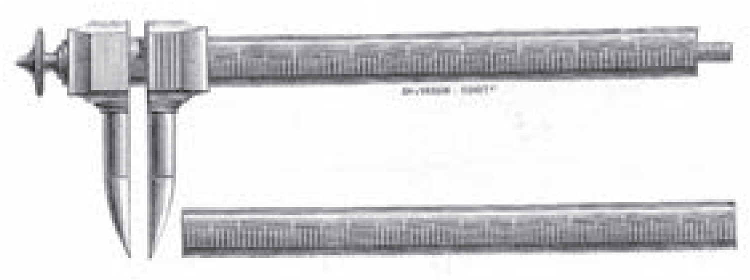

Fig. 9.
Sliding aesthesiometer with ivory points created
by the instrument maker Charles Verdin (1890, p. 43).

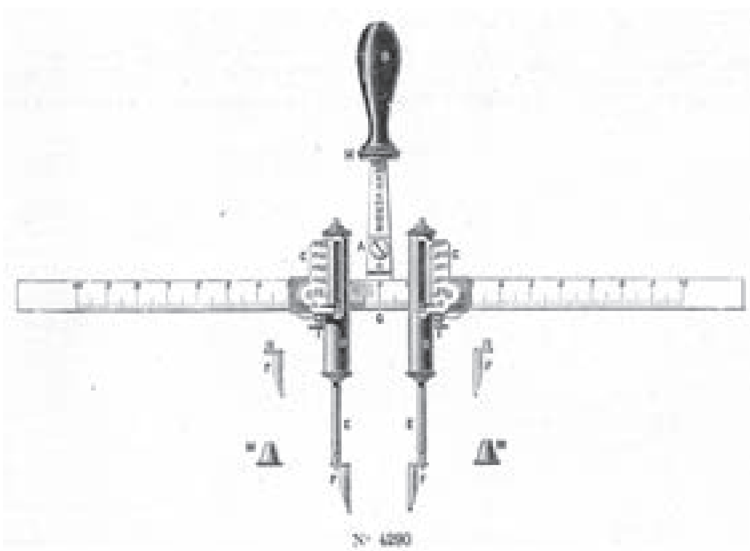

Fig. 10.
Dynamometric aesthesiometer with springs created by Verdin (1890, p. 65).

Griesbach (1895a, 1895b) tested his participants' tactile discrimination threshold with thin blunted points applied on the forehead, the zygomatic arch, the tip of the nose, the lower lip and the ball of the thumb of the right hand. Griesbach (1897)

disposed perpendicularly to a graduated rule, on which they slide. It is an advantage to know the distance between the points without having to compare it every time to an external rule. Moreover, in the ordinary compass, the points form an angle, they are not parallel, and their contact with the skin is oblique. As Bourdon has shown, this is a major source of errors, as it facilitates discrimination and decreases the threshold.'

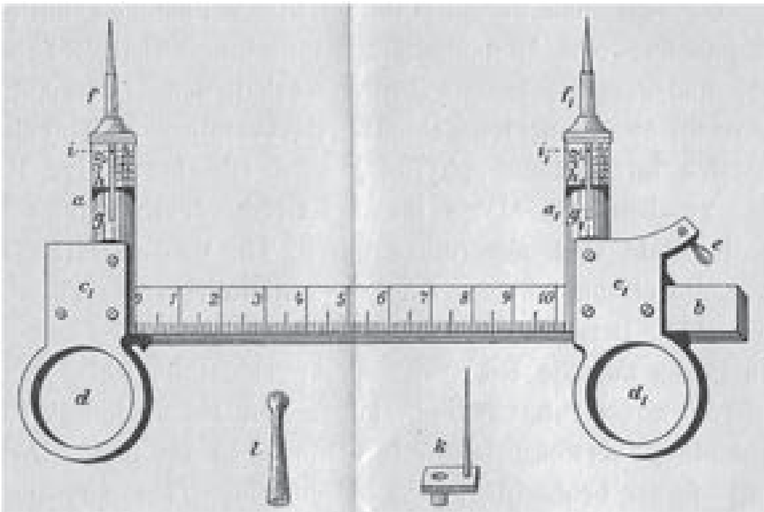

Fig. 11.
Griesbach's aesthesiometer (1897).

also built a dynamometric compass (Figure 11) for his work on aesthesiometry. Two metal tubes *g* and g_1 are attached to a metal scale *b* in such a way that *g* remains stationary, and g_1 movable. The tubes are screwed fast to the plates c_1 and c_2, which are equipped with the rings *d* and d_1 respectively. The plate c_2 has an opening for the scale *b*. The thumb and fore-finger of the right hand are placed in *d* and d_1, and the middle finger rests on the projection *e*. In each tube is a pointed metal shaft *f* and f_1, pushed outward by a spring. If one wishes to use blunt instead of sharp points it is only necessary to push the cap *l* over the shafts. Small indicators in the slit at i_1, and at a corresponding point (*i*) in the other tube, opposite *g*, as shown by dots, show the pressure on the points in grams (see Kotelmann, 1899).

2.2. Binet's skepticism toward aesthesiometry as a measure of mental fatigue

Griesbach's work (1895a), followed by that of Vannod (1896), Wagner (1898), and Blazek (1899), confirmed the effect of mental fatigue on tactile sensitivity. Binet was initially attracted by this procedure of finding the threshold of the sense of position to measure mental fatigue (Binet & Henri, 1898). However, in a new journal he had just created (*L'intermédiaire des biologistes*), his collaborator Victor Henri was skeptical, as shown by a question asked in the issue of 5 May 1898:

> Griesbach, Vannod and Wagner found that tactile sensitivity measured with Weber's compass is different in students after classes, and these authors have even proposed this procedure as a measure of mental fatigue induced by class. I tried to reproduce some of their results using this procedure, but I was not able to replicate their findings. Did I do something wrong? Are there some precautions to take when conducting experiments on students with this procedure? Is there no critical work in which the studies of Griesbach, Vannod and Wagner are carefully analyzed and their method precisely described? (p. 293).

Indeed, Binet's studies, done with his collaborator Henri, were starting to show that tactile sensitivity was not modulated by mental fatigue.

It was another of Binet's students, Jean Larguier des Bancels (1876–1961), who continued the study of aesthesiometry in Binet's lab. He used four procedures to measure mental fatigue (Larguier des Bancels, 1899): 1° the heart beat variability during rest and during intellectual work; 2° bodily temperature variability following intellectual work; 3° variability in muscular strength and 4° tactile sensitivity variability by Verdin's aesthesiometer. He observed that after work that was long enough for the subject to become aware of his mental fatigue, tactile sensitivity was diminished, but only in some areas. Muscular strength was heightened, and bodily temperature decreased. The blood flow pattern was also altered. He therefore concluded that, in line with Griesbach's results, intellectual work is followed by a diminished tactile sensitivity, but only in some areas. However, this conclusion was based on shaky data, since the decrease in tactile sensitivity was not total as might have been expected, but only local.

While some authors (Vannod, 1896; Wagner, 1898) confirmed that the procedure of tactile sensitivity was a sensitive method to measure mental fatigue in school children, other studies published in November 1899 in the American journal *Psychological Review* did not show any tactile sensitivity differences related to mental fatigue. James Henry Leuba (1867–1946), using Griesbach's (1895a) and Wagner's (1898) method, rejected aesthesiometry as a suitable measure of mental fatigue (Leuba, 1899). The work by G. B. Germann (1899) also reached similar conclusions. These American studies, reviewed in *L'Année psychologique*, led to Binet's skepticism, as his own research (in collaboration with Victor Henri) did not show conclusive results either. Binet (1900c) wrote the following:

> *We must admit that, two years ago, we organized with M. V. Henri several examinations of tactile sensitivity before and after classes. The tests done by M. Henri were not conclusive. These results were not published because they were not numerous enough to contradict facts which, at that time, were quite well established* (pp. 560–61).

They did not find that tactile sensitivity was lower after classes, as claimed by Griesbach (cf. Binet, 1903a, p. 105). At the same period, the work by Ritter (1900), Bolton (1902) and Kraepelin (1903) also went against aesthesiometry. In sum, this technique was at best not reliable as a measure of mental fatigue.

At the turn of the century, the effect of fatigue was studied from a physiological point of view by Binet's current (Aars & Larguier des Bancels, 1901; Clavière, 1901) and ex-collaborators (Joteyko, 1899, 1901; Féré, 1901). Binet first investigated the effect of intellectual work on food consumption (Binet, 1899, 1900a), before taking a more direct interest by administering attentional tests. Among his attentional tests, he included tactile sensitivity measured using a simple apparatus (Figure 12). He found that this procedure was good at measuring attention. He then made some technical modifications to the apparatus and built a new aesthesiometer (Figure 13) which enabled him to make an interesting psychological distinction between simplistic and interpretative individuals. Having extensively studied tactile sensitivity, Binet was naturally eager to see if students suffering from severe mental fatigue would show a decrease in this ability. Exceptional circumstances were at the root of his renewed interest in tactile sensitivity as a measure of mental fatigue.

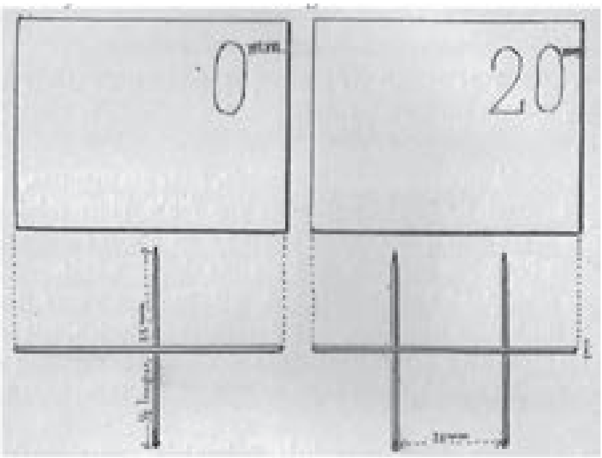

Fig. 12.
Apparatus with the points perpendicular to the surface of the cardboard (Roussel, 1905, p. 634). Instead of using Weber's compass, Binet and Henri created stimuli with fixed distances. These were pieces of cardboard with perpendicular points inserted through the holes. The left figure shows the cardboard with one point (distance = 0 mm) and the right one with two points 20 mm apart.

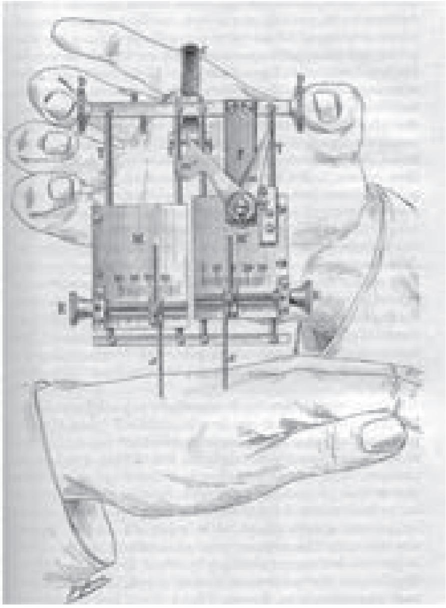

Fig. 13.
Binet's new aesthesiometer (Binet, 1901).

2.3. Aesthesiometry research at the *Société Libre pour l'Etude Psychologique de l'Enfant* (SLEPE)

Following obvious contradictions, Griesbach's results were discredited, and Binet became skeptical at first. However, after reading the work by Ley (1904), that showed a decrease in tactile sensitivity during mental fatigue in children suffering from debility, and by Schubert (1904), presented at the conference in school hygiene (4–9 April 1904, Nuremberg, Germany), he changed his mind. Binet returned to this issue, as he had a growing interest in psychopedagogic questions. Having participated in the foundation of the *Société Libre pour l'Etude Psychologique de l'Enfant* (SLEPE) in 1899, Binet generated interest in experimental pedagogy within this society and, after being elected president, created a special commission in charge of current issues, amongst which the question of the education of abnormal children, but also of mental fatigue.

Binet decided in October 1904 to create a special commission (Binet, 1904; Binet & Boitel, 1904; Boitel, 1904) to study mental fatigue and asked his collaborator Charles Chabot (1857–1924), who had attended the Nuremberg congress, to write a report (Chabot, 1905a, 1905b) on the controversy about aesthesiometry. This report was presented by Chabot at a session of the SLEPE on the 25 November 1904. He insisted on the procedures created by Griesbach to measure intellectual fatigue. He pointed out that neither muscular strength (*ergography*) nor dictation, copy errors or calculus (*psychological methods*) successfully measured mental fatigue. Although results presented at the conference seem to give some weight to the use of aesthesiometry (Vannod, 1904; Sakaki, 1904; Griesbach, 1904), more research was required to confirm these results. Binet believed it very likely that mental or physical fatigue produced a decrease in energy or, as suggested by Pierre Janet (1859–1947), a decrease in psychological tension (cf. Binet, 1905b).

The commission appointed by Binet started its work in this context (cf. Binet, 1905a). Griesbach (1905) had just published results confirming the relationship between mental fatigue and tactile sensitivity, and the goal of the commission was to test the reliability of this method.

The commission was divided in three groups that first met to agree on the technique that was to be used in their experiments. At the monthly meeting of the SLEPE (9 February 1905), Binet (1905c) presented the results of his own experiments. They had been done in collaboration with the inspectors Belot and Rauber, and Miss Billotey, the Principal of the *Ecole normale d'institutrices de la Seine*. One month of experimentation (December 1904) and sixty teachers were necessary for the investigation. For practical reasons, the technique consisted in applying not Weber's compass points, but needles attached to a cardboard (cf. Binet, 1905c), following the model (Figure 14) first developed by Buzenet (Roussel, 1905). Seven distances[6] between the points were used: 0 cm (only one point used) – 0.5 cm – 1 cm – 1.5 cm – 2 cm – 2.5 cm – 3 cm. The experimenter pressed the points on the back of the participant's hand and asked the participant how many points he felt. The order of presentation was predetermined, such that the distance contrast between two consecutive stimulations was maximized (1 cm, then 3, then 0, then 1.5, etc.). The series consisted of 56 stimulations (each distance repeated 8 times). The degree of sensitivity was positively correlated with the number of double perceptions for small distances, and the degree of attention was negatively correlated with the number of unique perceptions for large distances. The experiments on children were conducted as follows: An initial examination of sensitivity was done on each student, in the morning, before the beginning of the

[6] Binet (1901) used a procedure that combined the advantages of two other procedures used since Weber. Binet called this 'the procedure of irregular variations' (cf. Binet, 1903a). This mixed procedure combined two classical methods: the procedure of minimal changes (method of limits) and the procedure of false and true cases (constant method). All distances were presented, from the smallest to the largest (as in the procedure of minimal changes), but in a pseudo random order. Each distance was repeated the same number of times, and this pseudo random order was the same for each participant. In the majority of his experiments, Binet used a small number of distances (0, 0.5, 1, 1.5, 2, 2.5, 3 cm). These distances were appropriate to discriminate the tactile sensitivity of the dorsal part of the left hand (a distance of 3 cm between the points almost always resulted in the correct feeling of two touches). '*This mixed procedure, that gave me full satisfaction despite its slowness, is starting to be famous. We can call it the procedure of irregular variations.*' (Binet, 1903a, p. 113).

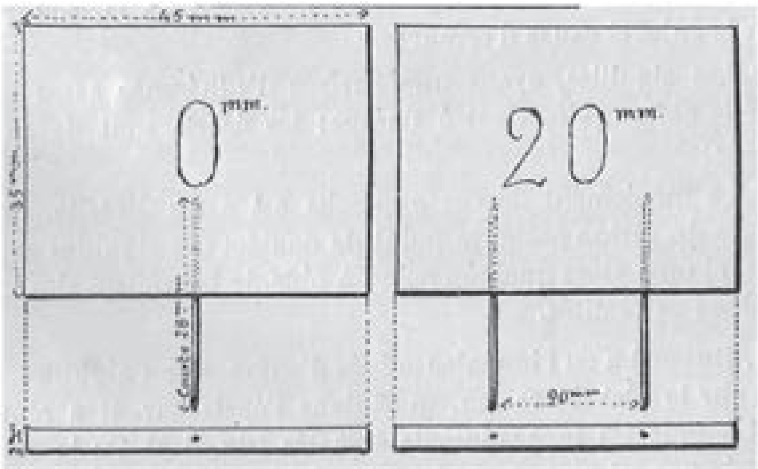

Fig. 14.
Cardboard apparatus with parallel points (Roussel, 1905, p. 634) presented by P. Buzenet. As the models with perpendicular points had a small contact surface with the cardboard, the distance between the points increased with time. Moreover, the cardboard masked the contact with the skin. To improve the reliability of this instrument, Buzenet had the ingenious idea of inserting the points sideways in the cardboard rather than through the middle.

class. Then, he/she was given a difficult task to carry out, such as calculus or problem solving. At the end of this exercise, the teacher immediately reassessed tactile sensitivity on the same skin area. The two examinations, each 10 min long, were done in similar conditions. The schoolchild was alone, in a calm room. The results of these first experiments (10–13 December 1904) showed (Binet, 1905b, 1905c) substantial inter-individual differences in schoolchildren. Thus, two measures were needed, before and after intellectual work, and had to be compared within each child. The degree of tactile sensitivity (measured by the number of double perceptions), decreased by 5% in boys (38%–33%) following intellectual work. For girls, the same procedure gave 40% at the initial examination, then 30% after intellectual activity. Concerning the degree of voluntary attention (measured by distraction errors on high distances, i. e. 2, 2.5 and 3 cm), no significant difference was found between the initial and the second examination. The effect of intellectual work seemed to affect only the degree of tactile sensitivity.

It turned out that Griesbach and his students had been right in affirming at the 1904 Nuremberg Conference that mental fatigue produced a decrease in tactile sensitivity. But was this fact of great interest for pedagogy, knowing that the size of the effect was very small? Binet wanted to go further by analyzing the results from the point of view of individual psychology (Binet & Henri, 1896; see Nicolas, Coubart, & Lubart, 2014). Was every schoolchild affected to the same extent by mental fatigue? Or did only a small proportion suffer from a massive effect? Binet discovered that the schoolchildren could be classified into 3 categories. 1° 39 children presented almost no differences between the first and the second examination. Maybe they were more vigorous and fatigue-resistant than the others. 2° 31 children presented considerable differences in tactile sensitivity. 3° lastly, 5 children presented increased tactile sensitivity following intellectual work. This allowed Binet to conclude that Griesbach's procedure was only significantly sensitive for about half of the schoolchildren, and only very few presented an inverse pattern.

As a wise experimental psychologist, Binet (1905c) decided to replicate this experiment and add a control group. Indeed, he had foreseen a potential methodological issue. In the first experiment, in order to determine whether a schoolchild had a decreased tactile sensitivity, he underwent two examinations, before and after the intellectual activity. However, the two examinations were not similar: the first time, the child did not know what the experimenter wanted from him/her, and he may have been upset, scared or surprised. These emotions could have altered his perceptions, judgment and answers. For the second examination, the schoolchild was trained in his judgment about tactile sensitivity. A control condition was therefore essential. Binet chose a group of children, measured their tactile sensitivity in the morning and then did a second examination the next day at the same time, before class, to ascertain whether tactile sensitivity varied in the absence of intellectual work. The results of this new experiment conducted on the 30 and 31 December 1904 showed that: 1° tactile sensitivity decreased after intellectual work (replication of the first experiment); 2° there was no difference in tactile sensitivity in the absence of intellectual work (after a full night's sleep). Thus, the variation in tactile sensitivity was caused by intellectual work. '*It is up to teachers to decide whether our results are of practical relevance, if the measurement of mental fatigue can inform us about the difficulty of school work, and if we can take it as a start to elucidate the many issues of school hygiene that are currently debated by physicians*' (Binet, 1905c, p. 652). The details of his report were published in June 1905 in l'*Année psychologique* (Binet, 1905b), along with new studies done with Simon, that supported his previous conclusions. Binet also presented studies carried out with Blocq's sphygmometer showing that mental fatigue decreased the sensitivity to pain.

3. *Conclusion*

The issue of mental fatigue led educators and psychologists to investigate the validity of aesthesiometry as a measure of mental and physical fatigue in schoolchildren. The educator and hygienist Griesbach was the first to show, in 1895, that the threshold of tactile sensitivity increased with fatigue. It was the first objective criterion of mental fatigue to be obtained following the heated debates in France and Germany. However, after the first successful results, the validity of this procedure was quickly questioned by numerous scientists, in particular the German school of Kraepelin. The debate seemed to be over and the procedure defective. In 1904–05, during the Nuremberg Conference (Schuyten, 1904), new experimental data supported Griesbach's (1895a) conclusions, despite the growing number of criticisms. Binet joined the debate, strengthened by his experience in the field of aesthesiometry, having himself developed new types of aesthesiometers (e.g. Binet, 1901). In his new experimental investigations on fatigue, he chose to use the version of the equipment suggested by his student Henri: cardboards pierced with needles, where the distances between the two points were fixed in advance. The experimenter had in front of him the various cardboards, ordered by distance between the points. To test the validity of this procedure to study mental fatigue, Binet conducted several experiments that supported Griesbach's (1895a, 1905) conclusions. From this date on, experimental data supporting this contested reality increased. But was this procedure of any practical use to teaching?

As suggested by Claparède (1909, p. 191), the question of fatigue is no doubt the most important one in teaching, for it involves the study of the organism's resistance to work. The procedures used could be divided into two categories: 1° psychological, by assessing the decrease in work performance (e.g., dictation, calculus, copying, etc.) that followed the state of fatigue and 2°, psychophysiological, by measuring the modifications induced by fatigue on several functions such as muscular strength (cf. Binet & Vaschide, 1898a, 1898b, 1898c; Clavière, 1901; Mosso, 1891, 1894) or sensitivity. For Claparède (1909, p. 198), aesthesiometry presented practical problems (it was complicated to use) as well as theoretical ones (are the variations in sensitivity proportional to variations in fatigue itself or are they the consequence of other factors such as attention, interest, habit, etc.?). However, this procedure encountered some success until up to the first world war, judging by the number of new publications on the subject (e.g. Abelson, 1908; Schuyten, 1906, 1908), before fading into oblivion. Nevertheless, the use of an objective test of mental fatigue should be continued, as done by Binet and his contemporaries. Binet opened the way for a rigorous experimental psychology interested in the practical consequences of its advances.

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