THE TIME TAKEN UP BY CEREBRAL OPERATIONS.[1]
James McKeen Cattell (1887)

Classics in the History of Psychology

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THE TIME TAKEN UP BY CEREBRAL OPERATIONS.[1]
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Part 4 of 4

IV. The Will-time.[2]

In the experiments described in the foregoing section the motion to be made was always the same, and took up the same or about the same time. In this section the nature of the motion depends on the nature of the impression. The experiments about to be described will throw further light on the Perception-time, but we shall find in addition a variable Will- (or Motor) time. The perception-process, further, is different from what we considered in the foregoing section: then the observer expected a certain impression and saw whether it was present or not; in the experiments now to be described the observer, not awaiting a given impression, had to identify the one occurring. We might perhaps expect the perception to be more difficult and consequently to last longer in the latter case; the experiments however show that there can be no great difference in the time.

Experiments have been made in this direction by Donders[3] and others, they letting the observer lift his right hand if (for example) the light is red, the left if it is blue. Under Wundt's direction Merkel[4] extended this method, the observer lifting a different finger for each of ten different impressions. My first experiments (carried out in the winter 1883-4) were made with aid of electric lights, as above described, and were similar to those of previous experimenters; they gave as the time for distinguishing the colour and choosing the motion 120s for B, 168 for C. Afterwards I used the gravity chronoscope, which enabled me to use daylight reflected from coloured surfaces. The current controlling the chronoscope was led through two keys (K and K' Fig. 8, MIND 42), the observer holding one closed with his right, the other with his left hand. Two colours, say red and blue, were used in the same [p. 525] series of experiments. If red appeared the observer lifted his right hand, if blue his left. The times are given in Table XXIX., the pairs of colours used being red and blue, and green and yellow. The reaction on red and on green was made with the right hand, on blue and on yellow with the left. Each number gives the average of six series (78 reactions in the uncorrected series).

TABLE XXIX.

		B				C			
		R	V	R'	V'	R	V	R'	V'
27.XI.—2.XII.	Red....	291	27	289	18	342	39	322	32
	Blue...	296	27	296	18	332	25	320	22
1.—5. XII.....	Green..	289	25	286	17	354	32	351	18
	Yellow	303	28	306	20	334	34	332	23
	A.....	295	27	294	18	340	32	331	24
	False...	9				3			

If from the average time for the four colours we substract[sic] the simple reaction-time, we find that it took B 145, C 190s to distinguish the colour and find the proper motion. If these times are compared with those given in the preceding section (Table XVI.) we find that it took B 18, C 34s longer to send out the proper and corresponding motion, than the command sending out a motion already determined. As I have already remarked, the perception-process is slightly different in the two cases; it being necessary in the first to see whether the light is red or blue, in the second only to recognise the red light. The results of the experiments show that there can scarcely be a difference in the times taken up by the two processes.

Quite a similar method was used with letters, the observer lifting his right hand if A was present, his left hand if Z. The numbers given in the Table are taken from six series.

TABLE XXX.

		B				C			
		R	V	R′	V′	R	V	R′	V′
4.—10. XII.....	A.....	328	27	324	18	379	42	370	30
	Z.....	339	23	336	15	382	34	379	22
	A.....	333	25	330	16	380	38	374	26
	False....	8				3			

[p. 526] The perception-time was thus for B 38, for C 40s longer than for colours, and the will-time for B 11, for C 43s longer for the choice between two motions than for the choice between making a motion and not making it.

In most of my experiments the motion corresponding to the impression was made with the organs of speech. I consider the time of special interest, as we are constantly reading a word, naming a colour, &c. In the experiments first to be considered two impressions were used; the observer did not know which was to come, but named the one occurring as soon as possible after seeing it. The motion was registered by means of the sound-key. These experiments are an extension of those given in Tables XVIII., XXII., XXVII. and XXVIII. There the observer made a determined motion (i.e., named an expected object), here the motion had to be found after the impression had been distinguished. The relation between the processes is exactly the same as when the motion is made with the hand, the only difference being that we are constantly giving the name blue (for example) to a certain colour, whereas the association between a motion of the left hand and the colour blue must be made for the experiments. The impressions were taken in pairs as indicated in Table XXXI. 26 reactions were made as usual in a series, 13 on each of the two impressions.

These results in Table XXXI., when compared with those given in Tables XVIII., XXII., XXVII. and XXVIII., give the increased will-times shown in Table XXXII.

We have already seen that with the hand B needed less additional time than C to make the choice between two motions: the difference between the two observers is still more marked when the motions are made with the speech organs. Table XXXII. is further interesting in showing a difference between letters and words on the one hand, and colours and pictures on the other. The association between a printed letter or word and its name requires less time, and is consequently closer than between a colour or picture and its name. We can understand this, as the former association is being more continually practised; still we could not have foreseen it, as the association between a colour or object and its name is formed long before we learn how to read.

In the experiments now to be described there were not two objects and two corresponding motions, but a large number of objects; the one occurring to be named by the observer. In this case we determine the time it takes to see and name an impression, as a word or a colour. We have in the preceding section determined approximately the time taken to see an object: the difference between the two times gives us the time it takes to name the object. We shall first consider the time needed to see and name a letter. All the letters of the alphabet (capital letters of the largest size in the text of

MIND) were used, each occurring once in the course of the series. After thirteen series had been [p. 527] made, the times for the separate letters were averaged together, so that we get the average of thirteen determinations on each letter; these series were corrected in the usual way, the three reactions varying most from the corrected average being dropped.

TABLE XXXI.

		B		C				B		C	
		R	R′	R	R′			R	R′	R	R′
17. II.	A	346	353	439	440	19. II.	Mind	339	332	432	435
	Z	338	341	398	390		Life	294	298	406	401
19.	B	366	366	415	420	21.	Time	296	305	379	382
	M	338	332	435	434		House	285	291	368	363
21.	E	326	321	384	383	24.	Child	355	350	410	415
	S	300	294	391	386		Year	361	364	409	411
24.	P	354	352	387	382		Truth	303	297	392	390
	T	350	341	436	429		Name	329	324	397	399
26.	O	292	296	425	421	26.	Light	339	339	421	424
	L	323	308	412	408		Ship	294	298	396	395
	A	333	330	412	409			319	320	401	401
	AV	24	17	28	19			24	16	21	14
17. II.	Red	342	329	472	479	17. II.	Watch	350	343	458	447
	Blue	317	322	441	447		Ship	376	387	424	422
19.	Green	303	298	484	474	19.	Eye	369	367	495	488
	Yellow	309	301	499	502		Hand	346	333	455	445
21.	Black	347	354	386	382	21.	Tree	340	336	455	459
	Pink	298	305	394	376		Bird	343	339	451	447
24.	Violet	293	288	395	370	24.	Fish	337	345	382	376
	Orange	276	270	433	441		Leaf	333	339	430	424
26.	Brown	323	325	421	431	26.	Hat	336	344	407	412
	Gray	331	337	453	446		Shoe	346	342	415	403
	A	314	313	438	435			348	347	437	432
	AV	27	18	41	36			31	20	44	31

TABLE XXXII.

	B	C
Letters	+ 15	+ 37
Words	− 2	+ 33
Colours	+ 24	+ 101
Pictures	+ 39	+ 74

[p. 528] As the determinations for the same letter were made at different times we find the mean variation larger than usual. Table XXXIII. gives besides the results obtained with aid of the sound-key, series made with aid of a second observer. The first observer simply named the letter as quickly as possible, and the second observer made the reaction on the sound in the manner above described. Mr. Wolfe acted as second observer; in the Table I have subtracted his reaction-time on sound (150σ) and his mean variation (10σ)).

TABLE XXXIII.

	Second Observer. 9.—30. I.						Sound-Key. 5.—19. II.					
	B			C			B			C		
	R	V	R′	R	V	R′	R	V	R′	R	V	R′
A	398	25	405	458	43	440	430	18	396	462	38	476
B	444	30	436	471	53	457	414	26	406	418	30	413
C	466	36	477	450	22	453	417	29	417	421	28	424
D	421	18	417	454	31	454	394	51	400	412	15	411
E	400	11	402	445	9	447	396	30	397	425	28	424
F	432	31	434	442	21	446	405	30	412	414	26	420
G	453	31	446	483	24	474	402	48	395	427	14	426
H	435	20	441	423	13	417	356	20	352	429	26	422
I	395	26	403	433	25	429	394	24	394	449	36	451
J	408	29	417	473	44	472	399	42	410	417	21	415
K	432	18	438	474	34	463	395	25	401	415	27	409
L	412	20	418	463	47	457	393	22	397	427	34	423
M	421	44	400	435	16	425	389	21	395	418	26	422
N	429	38	419	453	19	460	384	32	390	415	36	422
O	410	15	404	440	32	436	395	19	392	411	15	409
P	459	64	442	462	23	455	392	19	398	395	15	393
Q	446	28	461	480	22	469	428	34	438	413	22	418
R	422	20	435	462	20	469	385	28	389	443	18	446
S	431	33	431	471	38	479	391	27	394	412	22	410
T	425	25	432	446	34	454	398	36	390	414	18	409
U	428	22	434	461	47	471	391	22	396	439	14	441
V	463	32	450	465	29	461	383	20	378	428	26	423
W	421	42	405	485	16	481	353	26	364	435	24	432
X	465	46	471	452	25	460	381	31	388	405	29	412
Y	433	20	446	501	26	493	405	44	415	458	33	463
Z	431	12	432	499	37	507	393	19	392	426	22	421
A	430		431	461		459	395		396	424		424
AV		28	14		29	16		29	19		25	17

We thus see that it takes the observers about four-tenths of a second to see and name (i.e., read) a letter. In this connexion [p. 529] results I have already published[5] should be considered. I there determined by two distinct methods the time it takes to see and name letters. In most of the experiments, however, the observer while seeing and naming one letter could begin to see and name the one or ones following, so that the processes overlapped and the times became much shorter, namely 279s for B, 224 for C. The times were still further shortened (becoming 96s for B, 89 for C) when the letters made words. Why B's times should be longer than C's under these circumstances and shorter for a single letter I do not know. We found in the preceding section that it took B 119, C 116s to perceive a letter. Supposing the perception-time to be the same in both cases, B needed 143s, C 176 to find the name belonging to a letter. It should be added that in later series of experiments B's time became shorter. This method of determining the relative legibility of the several letters has an advantage over that in the previous section in so far as all the letters occur in the same series; but it is greatly complicated by the fact that the time of pronouncing the several letters may be different, as also the motion registered by the sound-key or second observer.

Series were made on the German capital letters with the results given in

TABLE XXXIV.

	B				C			
	R	V	R′	V′	R	V	R′	V′
14. II.....	423	36	420	23	554	63	538	32
16.....	446	30	439	18	573	58	549	33
18.....	377	30	382	20	531	60	519	38
23.....	363	34	357	23	464	30	461	21
25.....	369	31	389	24	507	33	510	20
A.....	396	32	397	22	526	49	515	29
F.....	3				1			

Numbers of one, two and three places were further used, and the time it takes to see and name them was determined. I did not take numbers of more than three places, fearing that they might not be seen and read as wholes. The results are given in Table XXXV.; from which it will be seen that it took B 33, C 38s longer to see and name a number of two places than of one, and B 57, C 47s longer for a number of three than of two places.[6]

[p. 530]

TABLE XXXV.

	One place.				Two places.				Three places.			
	R	V	R′	V′	R	V	R′	V′	R	V	R′	V′
B												
30. III.....	318	14	317	9	357	26	358	16	413	39	417	20
2. IV.....	316	28	312	16	344	18	343	10	381	25	377	15
A.....	317	21	314	12	350	22	350	13	397	32	397	17
C												
30. III.....	390	28	397	18	424	32	423	22	476	31	503	24
2. IV.....	418	24	419	13	460	39	460	21	502	39	499	24
A.....	404	26	408	15	442	35	441	21	489	35	501	24

The time it takes to see and name a word was determined in the same way. Experiments were made on long and short English and German words, 26 of each sort being taken. In the case of the short words I made thirteen series, and found the time for the separate words as with the letters (Table XXXVII.). On the long words only five series (130 determinations) were made, and the times for the separate words were not calculated (Table XXXVI.).

TABLE XXXVI.

	English.				German.			
	B		C		B		C	
	R	R′	R	R′	R	R′	R	R′
14. II.	493	484	451	450	419	409	501	498
16	481	475	490	488	451	454	533	527
18	447	440	451	457	424	418	507	500
23	391	383	430	434	379	370	433	432
25	391	378	431	431	381	376	473	475
A	441	432	451	452	411	405	489	486
AV	37	21	20	13	31	20	24	15

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TABLE XXXVII.

	B		C			B		C	
5.—25. II	R	R′	R	R′	5.—26. II	R	R′	R	R′
Bond	393	397	407	405	Baum	367	367	423	423
Cause	395	394	423	428	Berg	382	385	414	417
Chair	398	390	415	411	Bild	366	365	428	424
Child	396	385	414	411	Brief	367	362	444	440
Death	397	399	410	405	Buch	377	381	441	443
Earth	405	414	409	406	Ding	380	379	432	435
Fact	358	355	389	385	Fluss	356	362	425	424
Faith	374	367	388	379	Form	350	354	407	409
Force	359	362	371	373	Gold	378	385	452	450
Head	366	368	367	362	Haus	326	322	405	403
House	366	367	385	388	Jahr	362	354	455	454
King	393	389	414	408	Kind	392	401	444	450
Life	388	394	430	424	Kunst	397	400	456	461
Light	396	394	418	414	Land	381	386	440	441
Love	386	375	409	404	Licht	363	379	441	441
Mind	421	426	422	418	Mann	396	403	447	439
Name	402	401	405	410	Nacht	401	392	451	447
Plan	395	390	388	396	Recht	333	327	446	445
Ship	380	384	385	390	Stadt	399	402	451	449
Slave	407	413	409	402	Stern	417	413	436	432
Song	385	387	387	389	Teil	375	370	430	424
Style	431	435	435	442	Tisch	381	385	446	449
Time	381	388	411	408	Traum	366	372	453	454
Truth	380	372	426	424	Volk	348	346	429	428
World	381	370	411	408	Welt	341	340	447	445
Year	393	384	415	412	Zahl	374	381	459	469
A	389	388	405	404		372	374	439	438
AV	30	20	21	14		25	18	22	14

An examination of the Tables shows that it took longer (in English B 52, C 46s, in German B 39, C 46s) to see and name a long than a short word. In both cases, of course, the beginning of the motion was registered; so the time occupied in pronouncing the word does not come into consideration. We further learn that it takes longer (for short words B 17, C 35s, for long words B 30, C 38s) to see and name a word in a foreign than in one's native language.[7] Comparing the results here reached with those given in the foregoing section, we find that to name a short word in his native language B needed 104, C 114s. We find further that B named a word in 39, C in 62s less time than a letter. [p. 532] This is not surprising; we are constantly reading and using words, much

more than letters; so the association between the concept and the name has become closer and takes place in less time.

The same method was used to determine the time it takes to see and name a colour. The ten colours taken occurred two to three times in a series, and the times for the separate colours (13 determinations) were afterwards averaged together. Table XXXVIII. gives the times as measured with aid of a second observer, and as directly registered. The order of the colours is that of the average time needed to name them, beginning with the colour most quickly named.

TABLE XXXVIII.

	Second Observer 9.—30. I.						Sound-Key. 5.—25. II.					
	B			C			B			C		
	R	V	R′	R	V	R′	R	V	R′	R	V	R′
Blue	551	47	530	633	40	643	443	56	438	518	34	515
Green	535	59	539	663	25	658	433	36	440	539	29	532
Red	503	37	491	638	46	658	492	57	504	576	61	559
Black	641	82	618	589	34	583	473	41	464	515	54	505
Yellow	574	33	563	660	17	656	481	70	490	588	54	575
Pink	614	105	615	714	62	699	503	75	485	614	92	578
Violet	621	52	613	688	73	659	552	56	558	603	32	611
Gray	568	57	586	860	119	841	447	63	426	714	91	697
Brown	641	104	630	978	130	990	532	83	515	625	85	603
Orange	669	56	659	910	122	876	584	96	566	718	76	730
A	592		584	733		726	494		489	601		591
AV		63	39		67	42		63	42		61	38

These results are interesting and were not foreseen. We found in the preceding section that it takes less time to perceive a colour than a letter or word; we now find that it takes comparatively a very long time (B 286, C 400s) to find the name of the colour. This was especially the case at first and for certain colours. The colour was recognised with ease, but the name could only be found (more especially by C) with great difficulty. The colours most frequently seen and named in our daily life, red, yellow, green, blue and black, were named with greater ease and in decidedly less time (B 61, C 150s) than the other five colours, pink, violet, orange, gray and brown. In the case of these latter colours the time was considerably shortened by practice.

[p. 533] The twenty-six pictures already described were in like manner seen and named (by B in German, by C in English), the times for the several pictures (13 determinations) being given in the following Table.

TABLE XXXIX.

	Picture of an	B		C			B		C	
		R	R′	R	R′		R	R′	R	R′
14.—26. II.	Anchor	489	463	552	535	Leaf	497	497	578	567
	Bird	515	507	569	566	Moon	496	504	588	587
	Bottle	489	479	572	561	Picture	475	486	587	574
	Candle	493	494	563	552	Scissors	447	453	558	558
	Chair	498	510	539	534	Ship	445	438	493	486
	Cross	485	470	586	591	Shoe	437	430	492	493
	Eye	496	476	500	503	Star	481	488	496	498
	Fish	462	454	497	487	Table	486	496	544	547
	Flower	495	479	568	586	Teapot	499	486	612	600
	Glass	480	466	585	596	Tree	457	449	524	517
	Hand	484	476	500	490	Umbrella	466	472	567	556
	Hat	419	415	454	446	Watch	461	462	567	562
	Hatchet	469	454	526	513					
	Key	477	467	561	560	A	477	472	545	541
						AV	46	30	40	25

We found in the foregoing section that pictures (and, we may assume, the objects themselves) can be seen in about the same time as colours; we now find that they can also be named in about the same time (by B in 251, by C in 278s) as the colours most frequently used. The difference in time for the several pictures is interesting; both B and C named the picture of a hat in the shortest time; B required the longest time to name 'bird' and 'teapot,' C to name 'teapot' and 'moon'. It is an interesting fact that the picture of a chair can be recognised in less time than the word 'chair,' but that it takes over a tenth of a second longer to name it.

It will be useful to collect together certain of the results of these experiments. In the following Table I do not give to the thousandth of a second the averages of the determinations made, but what from the experiments seems to be the time it takes B and C to perceive and find the name of the objects we have been considering.

[p. 534]

TABLE XL.

	B	C
Reaction-time for Light	150	150
Perception-time for Light	30	50
" " a Colour	90	100
" " a Picture	100	110
" " a Letter	120	120
" " a (short) Word	120	130
Will-time for Colours	280	400
" Pictures	250	280
" Letters	140	170
" Words	100	110

We have thus found the time it takes us to see and name the objects which we spend a great part of our life in seeing and naming. We have not been dealing with artificial processes or things outside the circle of our natural interests. If in the course of evolution, as is probable, the molecular arrangement of the nervous system becomes more sensitive and delicately balanced, we may suppose that the times taken up by our mental processes become shorter, and we live so much the longer in the same number of years. It will therefore be of great interest to make experiments such as these on the lower races, as well as on persons of different age, sex, occupation, &c.

V. The Influence of Attention, Fatigue and Practice on the Duration of Cerebral Operations.

We have seen that while the time of a reaction is somewhat lengthened when the brain cannot so well prepare itself, it does not vary greatly with different degrees of Attention. I have made similar determinations for cerebral operations in which complications have been added to the simple reaction-time. I chose as typical cases the time it takes to see a white surface and show this by a motion of the hand, and the time it takes to see and name a letter. On the one hand the observer tried by great concentration of the attention and effort to react as quickly as possible; on the other hand the impression was produced at irregular intervals (three-fourths to fifteen seconds), so that the brain could not be held in a maximum state of readiness.

We find, from Table XLI., under the two degrees of attention or preparation a difference in the times of seeing and reacting on the white surface of 75s for B, 15 for C; in the time of seeing and naming a letter 29s for B, 25 for C.

[p. 535]

TABLE XLI.

	Concentrated.				Distracted.			
	B		C		B		C	
	R	R′	R	R′	R	R′	R	R′
	White Surface.							
4. IV	192	194	236	234	333	321	273	278
5.	196	193	235	237	250	233	256	254
6.	186	191	230	231	244	234	234	229
7.	192	194	246	249	239	239	246	248
A	191	193	237	238	266	257	252	252
AV	13	6	13	10	38	23	16	9
	Letters.							
4. IV	334	335	395	398	387	388	441	442
	336	333	397	402	371	366	403	411
5.	335	337	404	410	373	377	432	435
6.	333	336	395	397	343	350	422	418
7.	331	333	410	408	340	339	427	426
A	334	335	400	403	363	364	425	426
AV	29	20	21	13	33	20	26	16

As I have given throughout this paper the dates on which the series were made and have not omitted any series, the results of continued Practice can be studied to advantage. B and C had previously had considerable practice in making simple reactions, but none in the other processes here considered. In the twenty series of reactions on light (Table I.) made during a period of six months, no reduction in the time is to be noticed. B's reaction-time was however shorter in 1884-5 than in 1883-4, as can be seen from Table VI., where his times, especially for light, are considerably longer than C's. I repeated at the close of the investigation the determinations made at the beginning in which the observer reacted on one of a number of colours, letters or words (the results are given in Tables XIX., XXIV., XXVII.), and found that the times had become shorter. I give the decrease in time.

	B	C
Colours	28	20
Letters	50	25
Words	54	35

[p. 536] As I have already mentioned, the time of naming the colours and pictures became shorter through practice. In some cases where the attention was distracted the brain accommodated itself to the changed conditions. It can be stated as a law that the times of cerebral operations become shorter as they become more automatic, but that a limit is reached beyond which further practice has little or no effect.

The investigation was concluded in April; in July, after an interval of three months during which no reactions were made, the times of the more important processes were again measured. The Table gives the results of five series of simple reactions on light and sound, of five series in which the observer showed by a motion of the hand that he had perceived a white surface, a letter and a colour, and of three series in which he perceived and named a letter, a word and a colour. The increase or decrease of the time is given in the column headed Df.

TABLE XLII.

	B					C				
	R	V	Df	R′	V′	R	V	Df	R′	V′
Light....	139	12	− 10	140	8	167	13	+ 17	167	9
Sound...	122	7	− 3	121	5	141	9	+ 16	139	6
White...	212	12	+ 1	211	6	254	13	+ 13	254	8
Letter...	305	22	+ 19	304	14	309	26	− 3	307	18
Colour...	258	22	− 1	256	17	289	24	− 4	284	15
Letter...	354	25	− 41	353	17	425	22	+ 1	428	14
Word....	331	17	− 58	330	12	410	20	+ 5	410	14
Colour...	402	33	− 92	400	23	609	71	+ 8	600	50

We now come to the effects of Fatigue. These, like the effects of attention, have been greatly overestimated, experimenters having made but few reactions in a series or at a sitting, fearing lest the observer should become fatigued and the times unduly long. In order to determine the influence of fatigue in successive reactions, I took thirty series of simple reactions on light and averaged all the first reactions (as also the mean variation of these reactions) together, all the second reactions, and so on through the twenty-six reactions of which the series was made up. In the same way I took two hundred series where the subject had to react (with the hand) after distinguishing an impression, and averaged all the first, second, &c. reactions together. The impressions were different in the different series, but of course the same throughout each series. In these series only thirteen determinations were made, but twenty-six mental processes took place, it being as fatiguing to see that the object was not there and keep from reacting, as to distinguish the object and react.

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TABLE XLIII.

	B		C			B		C			B		C	
	R	V	R	V		R	V	R	V		R	V	R	V
I.....	136	18	139	15	XIV ...	147	9	151	10	I.....	277	30	306	29
II.....	146	14	155	13	XV.....	147	9	151	8	II.....	287	25	308	22
III....	144	11	150	9	XVI...	149	12	148	8	III....	294	25	308	23
IV....	145	16	149	10	XVII..	152	12	154	12	IV....	298	22	316	28
V.....	143	9	149	10	XVIII.	152	8	152	10	V.....	297	25	314	23
VI....	142	13	149	13	XIX...	151	9	154	13	VI....	300	25	317	22
VII...	147	10	151	13	XX.....	148	10	151	12	VII...	292	21	318	24
VIII.	148	10	150	11	XXI...	150	13	146	9	VIII.	298	23	319	23
IX....	155	13	149	7	XXII..	152	12	150	10	IX....	299	20	319	23
X.....	145	9	151	9	XXIII.	147	8	148	12	X.....	297	23	322	24
XI....	143	13	147	9	XXIV.	152	13	144	10	XI....	297	23	319	22
XII...	154	14	147	13	XXV...	150	13	144	11	XII...	293	20	322	23
XIII.	153	16	152	11	XXVI.	150	15	150	10	XIII.	295	22	317	23
A.....						148	12	149	11		294	23	316	24

It will be seen that, though the difference is not great, the first reactions of a series are the shortest. It seems that in the first experiments the observer involuntarily strains his attention more, and so gives shorter times. This is the more marked the less automatic the process is; that is, with the white light than in the simple reaction, and in the case of B than in the case of C. The further course of the series shows no lengthening in the times or increase in the mean variation; so the brain is not considerably fatigued by making (or refraining from making) twenty-six reactions in succession.

In order further to investigate the effects of fatigue, I made extended series of experiments in which 1950 reactions were made in succession, the observer reacting almost continuously from early in the morning until late into the night. Three series (78 reactions) were made with light, then three series (39 determinations, but 78 mental processes) in which white light was distinguished and reacted on, then three series in which letters were seen and named, then two series in which associations were made, lastly three series of reactions on sound. This entire combination of series was repeated six times. The experiments were begun both days at 7:30 a.m. and were concluded in the case of C at 1:30 a.m., in the case of B at 11 p.m., short pauses being made for meals. One

series of each variety was made the following morning and again in the evening; in the case of C a further set of series the day after. In the Table I give the average time and mean variation of the first set of series, afterwards the increase or decrease as compared with these. I do not take up space to give the corrected series, as they scarcely differ from the others.

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TABLE XLIV.

		Light.		White Surface.		Letters.		Assoc.		Sound.	
		B									
31. III.	7·30 a.m....	157	12	198	21	344	25	733	103	139	9
	9·40 „	− 1	− 1	− 5	− 4	+ 10	+ 2	− 98	− 17	− 3	− 1
	1 p.m....	− 14	− 2	+ 9	− 4	− 7	+ 9	− 59	− 11	+ 11	+ 10
	2·50 „ ...	− 10	− 3	+ 9	+ 4	+ 4	+ 1	− 2	− 8	− 7	− 2
	6·55 „ ...	+ 1	− 2	+ 34	− 3	+ 12	+ 6	− 81	− 39	+ 3	+ 2
	8·50 „ ...	+ 5	+ 1	+ 20	− 2	+ 37	+ 5	− 228	+ 121	+ 10	+ 1
1. IV.	8·30 a.m....	+ 17	− 2	− 10	+ 1	+ 21	+ 9	+ 83	+ 2	− 16	− 2
	8 p.m....	+ 7	+ 3	+ 2	− 5	+ 1	+ 10	+ 153	+ 68	− 2	+ 5
		C									
26. III.	7·30 a.m....	156	10	247	12	439	23	827	125	144	13
	10·55 „ ...	+ 10	+ 3	− 17	+ 4	− 8	− 4	+ 9	+ 8	+ 2	− 3
	2·40 p.m....	+ 28	+ 5	+ 1	+ 9	+ 9	0	+ 12	+ 43	+ 15	+ 1
	7·20 „ ...	+ 19	+ 1	− 10	+ 7	+ 19	− 3	+ 58	+ 5	+ 15	+ 3
	9·20 „ ...	+ 33	+ 7	+ 6	+ 9	+ 37	+ 3	+ 163	+ 23	+ 19	− 4
	11·40 „ ...	+ 34	+ 8	+ 2	+ 4	+ 30	0	+ 111	+ 10	+ 11	0
27. III.	8·30 a.m....	+ 27	+ 1	+ 6	+ 7	− 3	+ 5	+ 19	+ 7	wanting	
	8 p.m....	+ 20	+ 5	− 2	+ 2	+ 11	− 3	− 12	− 41	+ 23	− 2
28.	8·30 am....	+ 25	+ 12	− 1	+ 5	− 5	− 3	+ 42	+ 44	− 6	− 1

The first result to be noted from the Table is the very slight effects of fatigue; in no case is the time lengthened more than a couple of hundredths of a second, and the mean variation is but little increased. We reach the unexpected result that the processes which are the most automatic (naming the letters, and C's simple reaction-time) are the most affected by fatigue. The determinations made on the following day show that B had recovered from all fatigue; in the case of C, however, the brain substance concerned in the simple reaction seems to have been so far exhausted that his reaction-time remained abnormally long for two days.

I think these experiments show that it is possible to apply scientific methods to the investigation of mind. We have determined the times required for those processes which make up a great part of our mental life, and found these times to be constant; they are no more arbitrary, no less dependent on fixed laws than, for example, the velocity of light. I shall soon print an account of experiments going a step farther and determining the times of mental processes more removed from psycho-physical operations having to do with sensation and motion.

Footnotes

[1] Concluded from MIND 42 and 43.

[2] I use the term 'Will-time' for lack of a better; in Germany 'Wahlzeit' is used. The motion is in most cases simply the result of the perception, and 'Association-time' might be used, were it not already taken up. 'Motor time' would perhaps best explain the process, but might cause confusion.

[3] Arch. für Anat. u. Physiol., 1868.

[4] Phil. Studien, ii, 1.

[5] Phil. Studien, ii. 4; MIND 41.

[6] See Friedrich, Phil. Studien, i. 1.

[7] See Cattell, Phil. Studien, ii. 4; MIND 41.

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