INFORMATION CAPACITY OF THE HUMAN MOTOR SYSTEM

A report of an experiment conducted
at Mathew Moss Middle School, in
Rochdall England, in 1982

By

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1. Literature Review

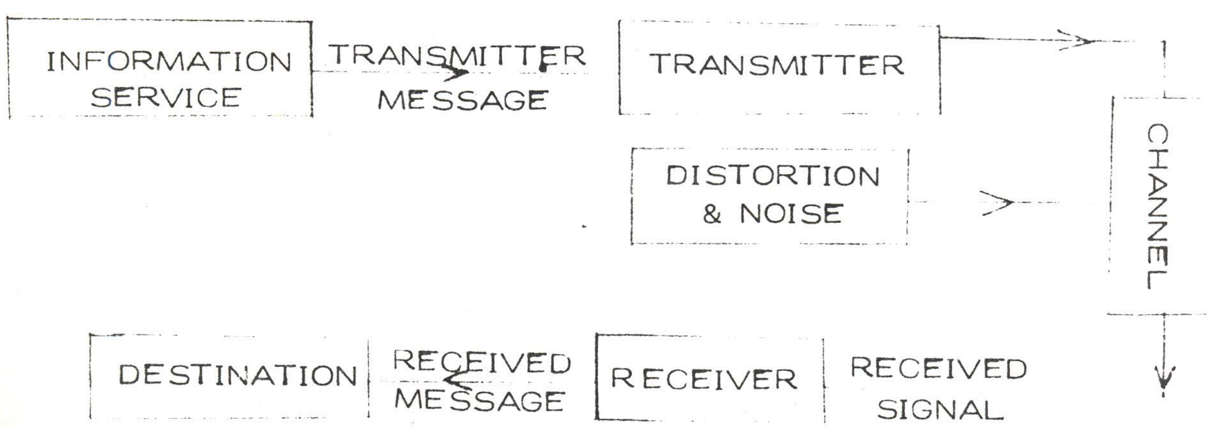
Information theory was originated by communications engineers in telephone laboratories (Hartly 1928, Shanon 1948), their interest being the problems of how quickly and accurately one can send messages over noisy telephone lines. From this experiment they developed the information theory as a means of discussing suchlike problems.

Information theory is an attempt to explain communication in a precise mathematical fashion. It is a mathematical technique for measuring the effectiveness of sign transmission in a man made system. What is measured is the speed or economy with which sign information can be brought about (Parry 1967). It is a useful concise means of explaining problems of communication, perception and motor performance (Cratty 1967). It involves the efficiency of encoding, transmission and decoding messages (Munn 1966). It is the rate of information transmission as a means of measuring skills (Fitts & Posner 1967).

Information theory is expressed in the form of a communication model where man's behaviour is conceived to be an information processing activity (Robb 1972). Singer gives a simple version, viz.

Singer (1968)

But Young offers a more detailed model as follows :



Young (1971)

Shannon and Weaver offer useful definitions of the terms used as follows :

(i) Information Source - produces a message or sequence of messages to be communicated to the receiving terminal.

(ii) Transmitter - operates on the message in some way to produce a signal suitable for transmission over the Channel.

(iii) Channel - is the medium used to transmit the signal from transmitter to receiver.

(iv) Receiver - performs the inverse operation of that done by the transmitter.

(v) Destination - is the person or thing for whom the message is intended.

The information source selects a desired message out of a set of possible messages. The selected message may consist of written or spoken word, or of pictures, music, etc. the transmitter changes this message into the signal which is sent over the communication channel from the transmitter to the receiver (Shannon & Weaver 1949).

Information should be thought of as the reduction of uncertainty since only this type of information can be expressed quantitively. (Parry 1967), In order for information to be conveyed, there must be some uncertainty. The amount of information potentially available increases with the amount of uncertainty in the situation, i.e. the amount of information increases with the number of possible things which might have occured. (Fitts & Posner 1967). Shannon and Weaver say "information is a measure of one's freedom of choice in selecting a message. The greater this freedom of choice and hence the greater the information, the greater is the uncertainty that the message actually selected is some particular one. Thus greater freedom of choice, greater uncertainty, greater information go hand in hand." (Shannon & Weaver 1949).

Fitts & Posner outline the stages of the development of concepts into a mathematical formula as follows :

> "In skills it is often the average information in a series of events which is desired. Each event contributes information in accordance with its probability. However any event occurs only as often as its probability."

To express the above considerations in quantitive terms it is necessary to include the following factors :

(i) Number of alternatives (N)

(ii) Probability (P)

(iii) Average of series of events (i = event)

Thus the following equation can be constructed :

(1) Information (H) as a function of (N)

$$H = Log_2 N$$

(2) Information as a function of N and P

$$H = Log^2\, {}^1/_P$$

(3) Information as a function of N and P in a sequence of events

$$H = {}_{i=1}^{N} \quad Pi\ Log_2\ {}^1/Pi$$

(Fitts & Posner 1967) draw the following conclusions on information transmission. viz

(i) The information transmission is that amount of the stimulus information which is represented in the subject's response.

(ii) Information transmission will be maximum when one and only one response always occurs when a given stimulus is presented. If any other response occurs, the amount of information transmitted will be reduced.

(iii) When the information transmitted per response is divided by the time it takes to respond, the rate at which information is transmitted is obtained.

Thus; Information transmission rate $= \dfrac{\text{Inform. transm. per Resp.}}{\text{Time taken to Respond}}$

(iv) The rate at which information is transmitted is useful for all tasks which place emphasis on speed.

BITS

The term "bits" in information is used to specify the quantity of information. Bits are transformed through symbolic coding into chunks of information. The term chunk refers to several bits of information which have been organised into a meaningful group. Such groups of information into larger categories or chunks enables man to retain more information. (Robb 1972).

CODING

For information to be transmitted the original stimulus must be encoded and after transmission decoded.

(Fitts and Posner 1967) explain coding as follows :

"A code consists of a population or alphabet of symbols and a system of rules or constraints among them. When rules are introduced which govern the order of symbols (such as in English) the code becomes redundant."

But (Parry 1967) explains coding as depending on selection. Thus "the power of attention seems to select information in line with the system's interests and to reject what falls outside them". Also, when "Limits of apprehension have been reached, human systems can transcend this limitation by organising input elements into more complex units that can in turn become objects of attention, e.g. the digits "1", "0", "6", "6", can through association with a famous event, be handled as a single unit".

NOISE

(Shannon & Weaver 1949) refer to noise in the following manner.

"In the process of being transmitted it is unfortunately characteristic that certain things are added to the signal which were not intended by the information source. These unwanted additions may be distortions in shape or shading of pictures, or errors in transmission, etc. All of these changes in the transmitted signal are called noise."

(Munn 1966) refers to noise as distortions of any sort which are irrelevant to or interfere with transmission of messages.

(Fitts & Posner 1967) refer to noise as the amount of apparently spontaneous variability in behaviour.

CHANNEL

(Singer 1968) suggests that every person has a channel capacity above which the information cannot be transferred. This capacity can be determined by increasing the input and measuring it with the responses, for if the material can be handled accurately, there will be few errors. With too much of an increase more errors are expected. Greater input results in increased output, to a point, as there is an asymptotic value for every channel, e.g. it is not difficult to distinguish among a few tones. When more tones are presented to the observer he will be able to recognise and distinguish a limited number of them. Singer also adds that "Studies have shown that an individual can increase the amount of information he can store. When the object is to memorise a series of numbers, more can be remembered if these numbers are recorded. If the channel capacity of the learner of motor activities could be determined the appropriate amount of material would be taught to him at one time. Too much material would be wasted and not monitored, too little would not promote maximum use of the time allotted.

(Shannon & Weaver 1949) describe channel capacity like this "Channel capacity is inferred as the maximum possible rate at which a channel can transmit information".

(Fitts & Posner 1969) say "Channel capacity refers to the rate at which information is transmitted, and not to the amount of information per response".

Welford theorised that movement time is determined more by central processes controlling movement than by any factors of muscular effort involved. Choice reaction time is primarily affected by the translation mechanism.

(Hick 1952) found that if the number of possible responses (key tapping in response to 10 lights) is taken as "N" and reaction time is plotted against Log (n+1), the observed reaction times for different numbers of signals lie in a straight line which also passes through the origin. Hick's law can thus be written as :

$$\text{Choice reaction time} = K \text{ Log } (n+1)$$

(where "K" is a constant)

Thus in making choice reaction times the subject gains information in the information theory sense of the term, at a constant rate.

(Hyman 1953) and (Bricker 1955) argue that uncertainty about when a signal will come and about which signal has arrived should be treated seperately and that it should be written as follows :

Choice reaction time = a + b Log.N, Where "a" and "b" are constants and "a" is equal to the simple reation time and caters for temporal uncertainty.

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2. Methodology

(a) Experimental Design

The experiment was based on that designed by (Fitts 1954) which involves application of information theory to a movement task involving speed and accuracy. Each subject was required to make twenty taps on two targets of fixed distances apart in as fast a time as possible. The amount of information each subject could process per unit time is regarded as an indication of the subject's "channel capacity".

Targets varied in amplitude, i.e. distance between the two centre lines of each target, and in width. An index of difficulty is calculated according to the formula :

$$ID = \log_2 \frac{2A}{W}$$

where A = amplitude of movement
W = width of target

(See appendix for targets).

(b) Experimental Procedure

Six thirteen year old subjects were taken randomly from a school physical education class. The subjects sat at one end of the room and took the test individually with the two experimenters at the other end. Each subject was given a trial on each target and asked to make twenty taps within the two targets as quickly and accurately as possible, with a pencil held in the preferred hand. They were asked to hold the pencil on the right hand target and on the word "Go" were to make twenty taps beginning with the left hand target. They were also told that their times for the tests would be noted. Speed and accuracy were equally stressed.

For actual testing, the instructions were repeated, and each subject was allowed one minute's rest between each test. One experimenter gave the instructions and recorded, while the other observed, timed and counted the twenty taps.

Indices of difficulty (ID) were chosen at :

$$
\begin{aligned}
ID = \log_2 \frac{2A}{W} &= 4 \\
&= 8 \\
&= 16 \\
&= 32 \\
&= 64
\end{aligned}
$$

IDs were tested in the order "4", "8", "16" and "64"; a graph was constructed by drawing a straight line of best fit through the plots obtained. From the first four tests ~~and~~ the time for ID "32" was then predicted. ID "32" was then tested without the prediction being related to the subject.

Additionally, six subjects were randomly selected and tested on two different ID "16"s as follows :

(1) $A = 4''$, $W = \frac{1}{2}''$

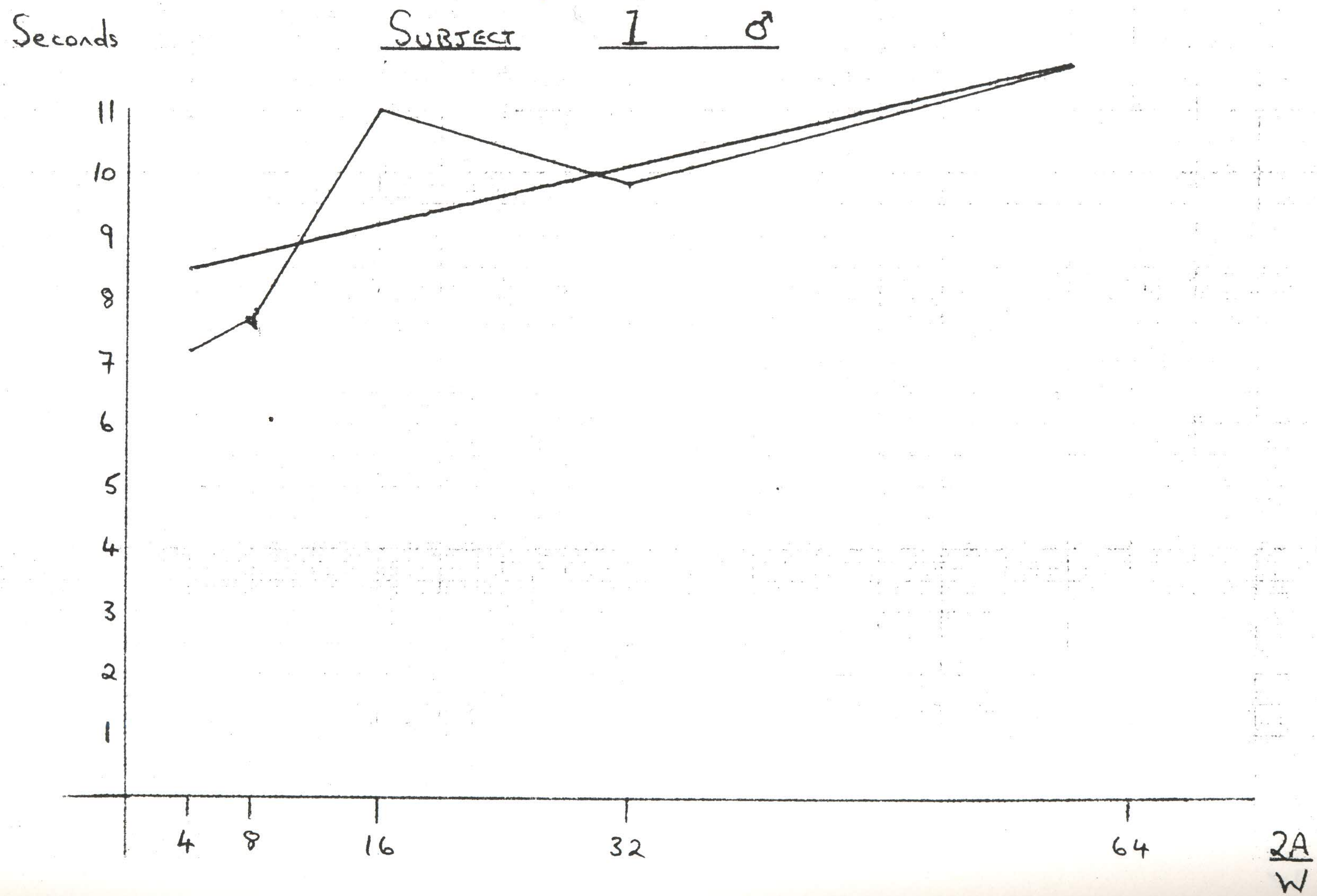
(2) $A = 2''$, $W = \frac{1}{4}''$

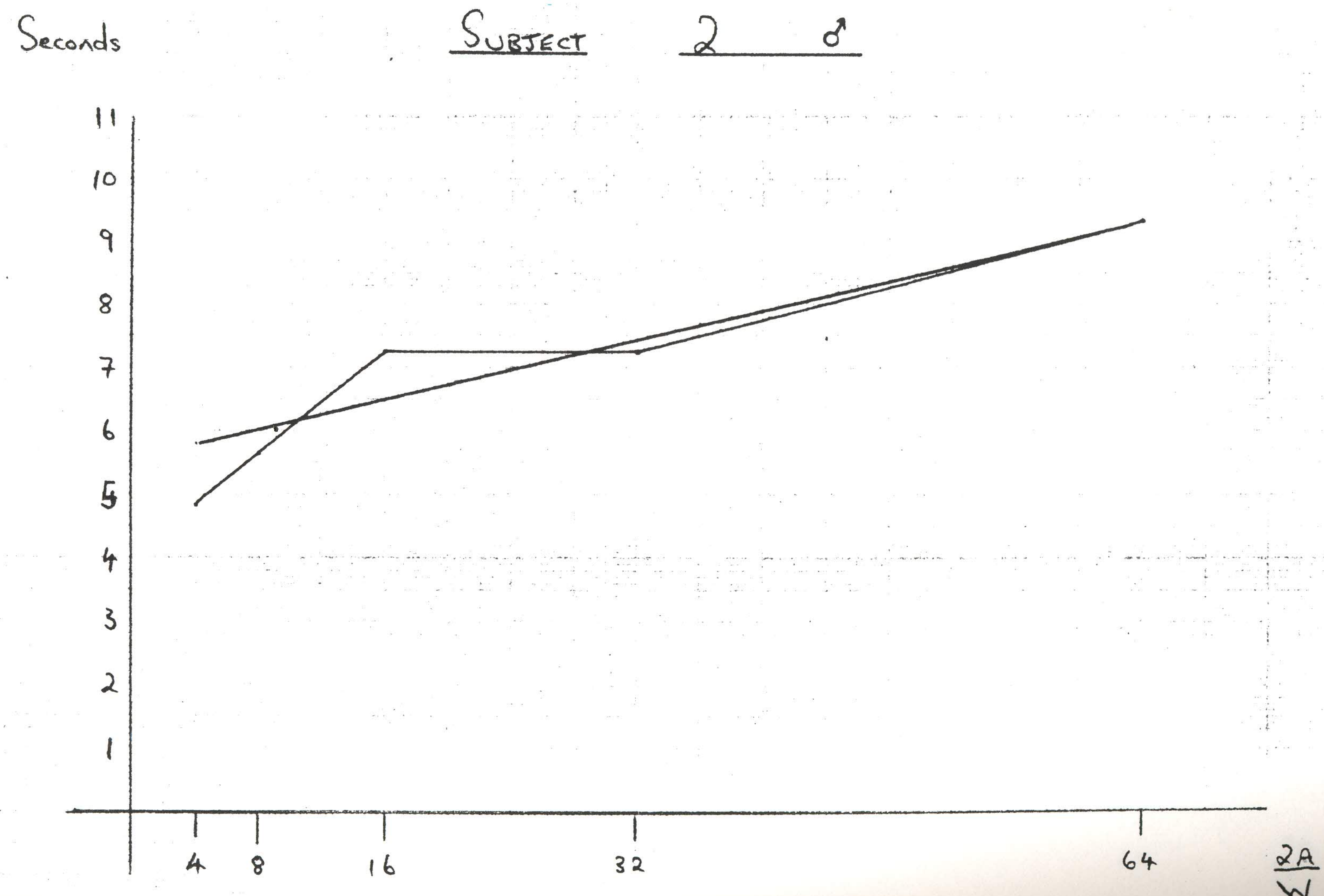
Instructions were given as before.

3(a) Table of Results (time in seconds)

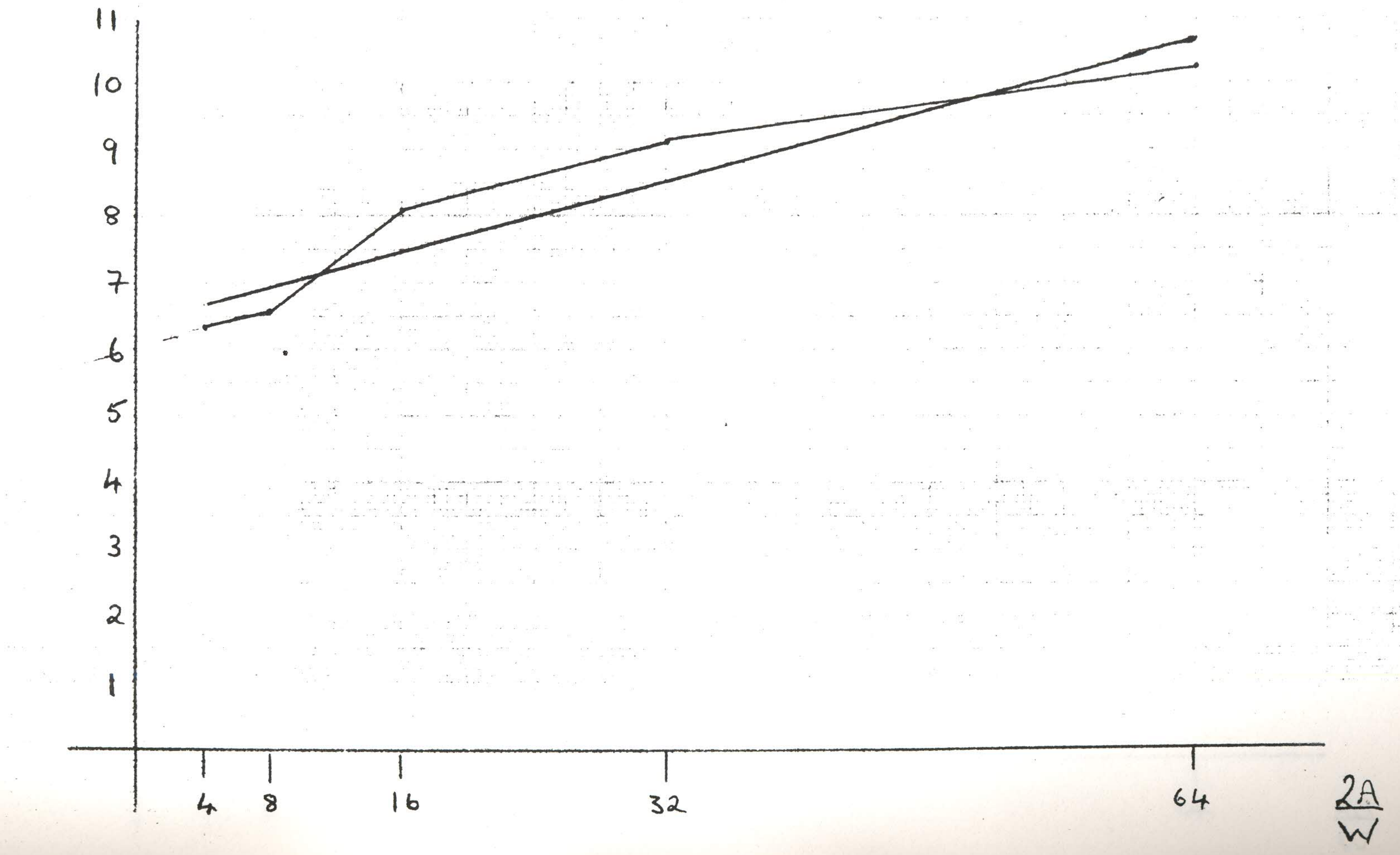
Boys — Index of Difficulty

Subjects	4	8	16	32		64
				Predict.	Actual	
1	7.18	7.68	11.01	10.1	9.82	11.67
2	4.82	5.64	7.27	7.4	7.23	9.35
3	6.35	6.60	8.08	8.5	9.13	10.25
4	5.13	5.66	6.18	6.5	6.70	7.75
5	6.31	9.20	8.41	7.8	6.33	7.42
6	7.47	7.52	7.06	8.4	9.67	8.66

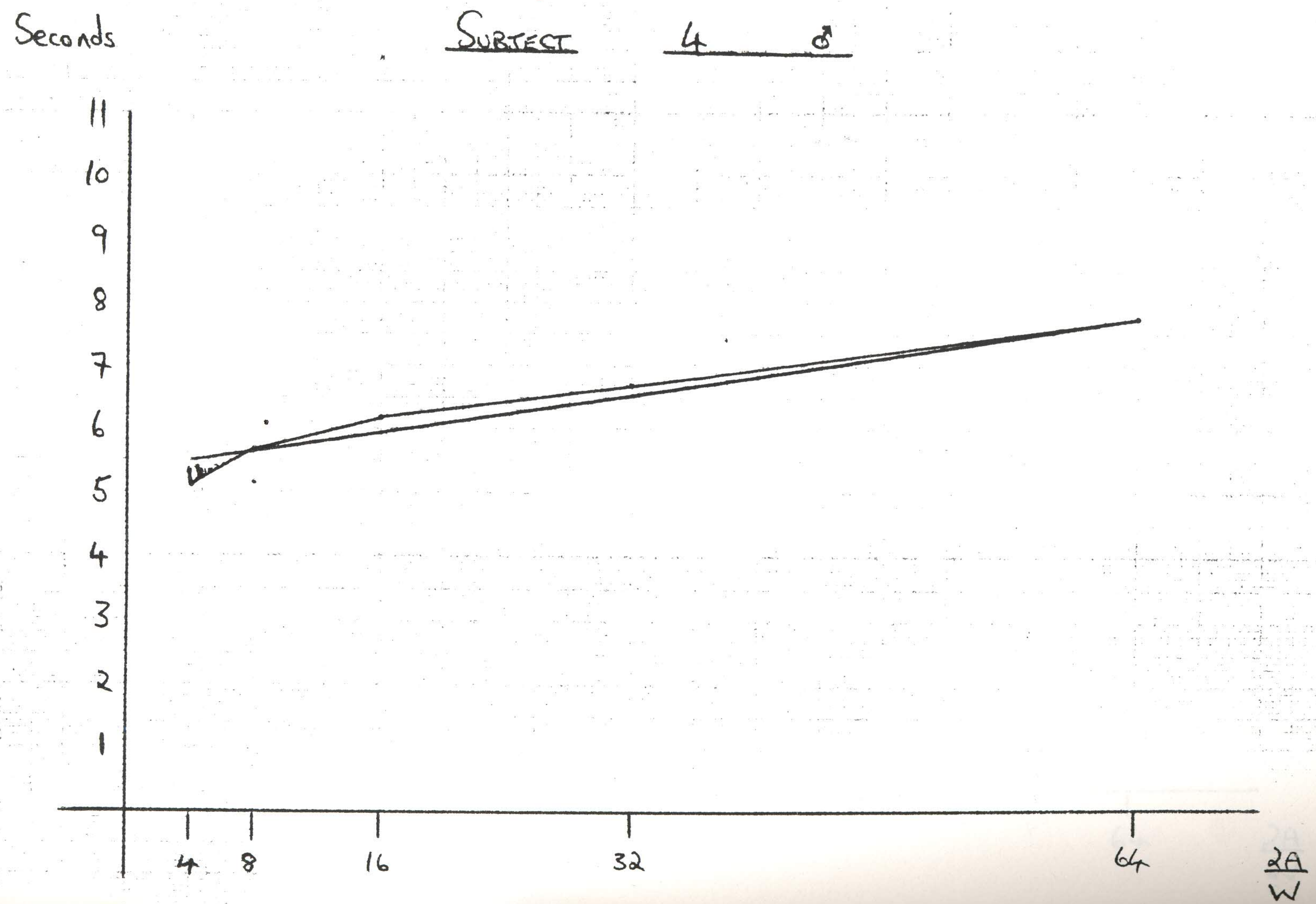

Seconds
SUBJECT I ♂
11
10
9
8
7
6
5
4
3
2
1
4
8
16
32
64
2A/W

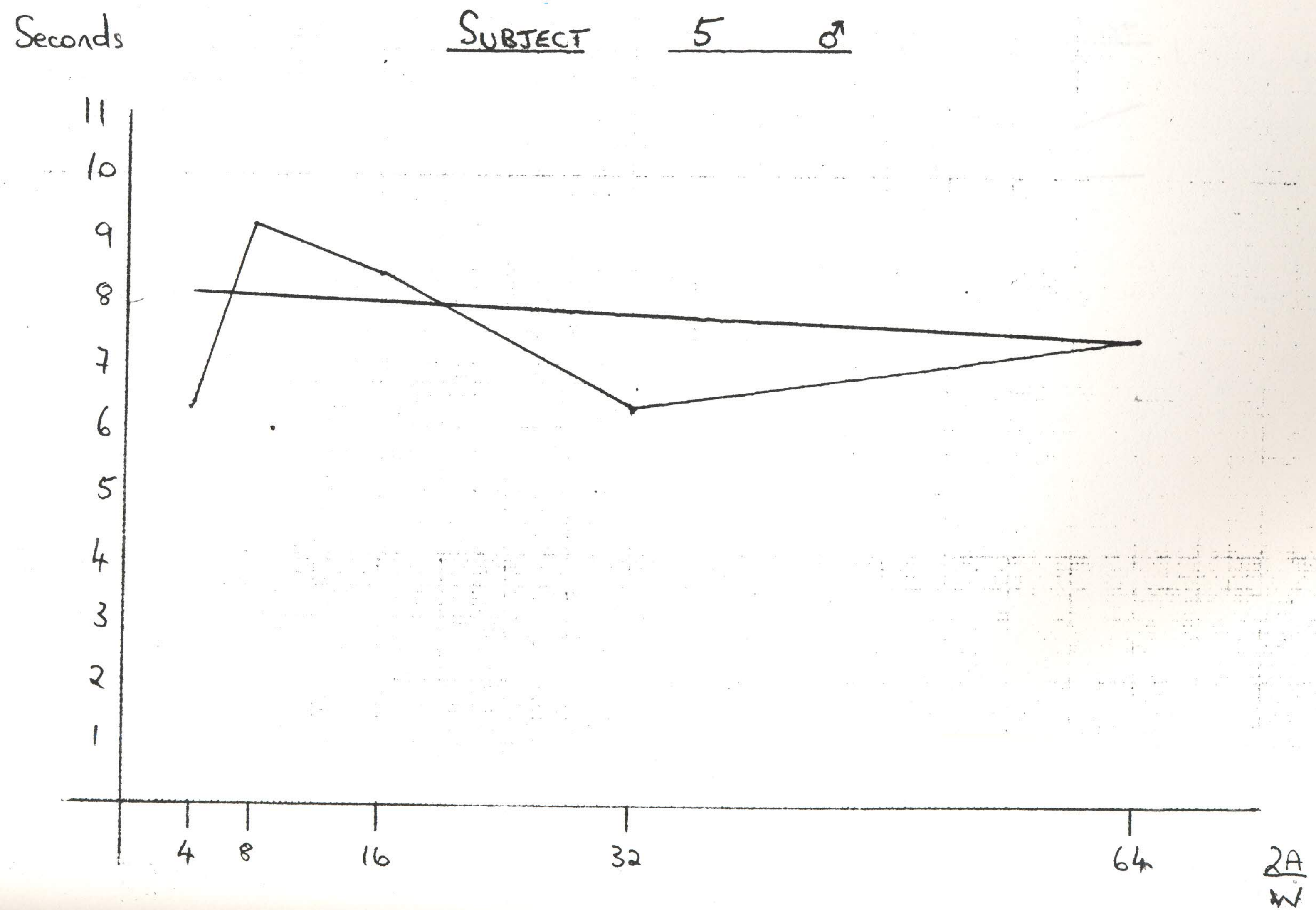

Seconds
SUBJECT 2 ♂
11
10
9
8
7
6
5
4
3
2
1
4
8
16
32
64
2A/W

Subject 3 ♂

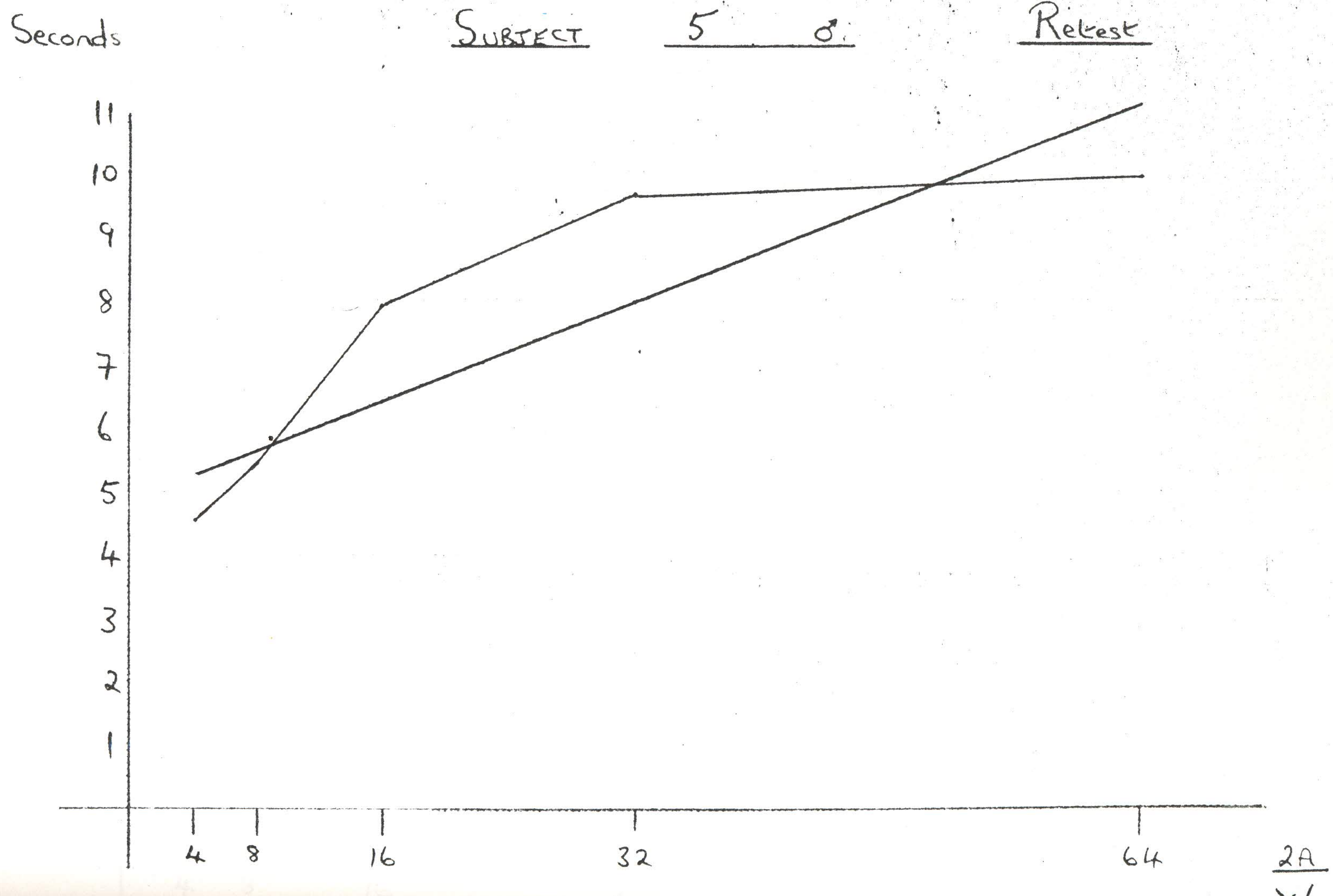


SUBJECT 4 ♂

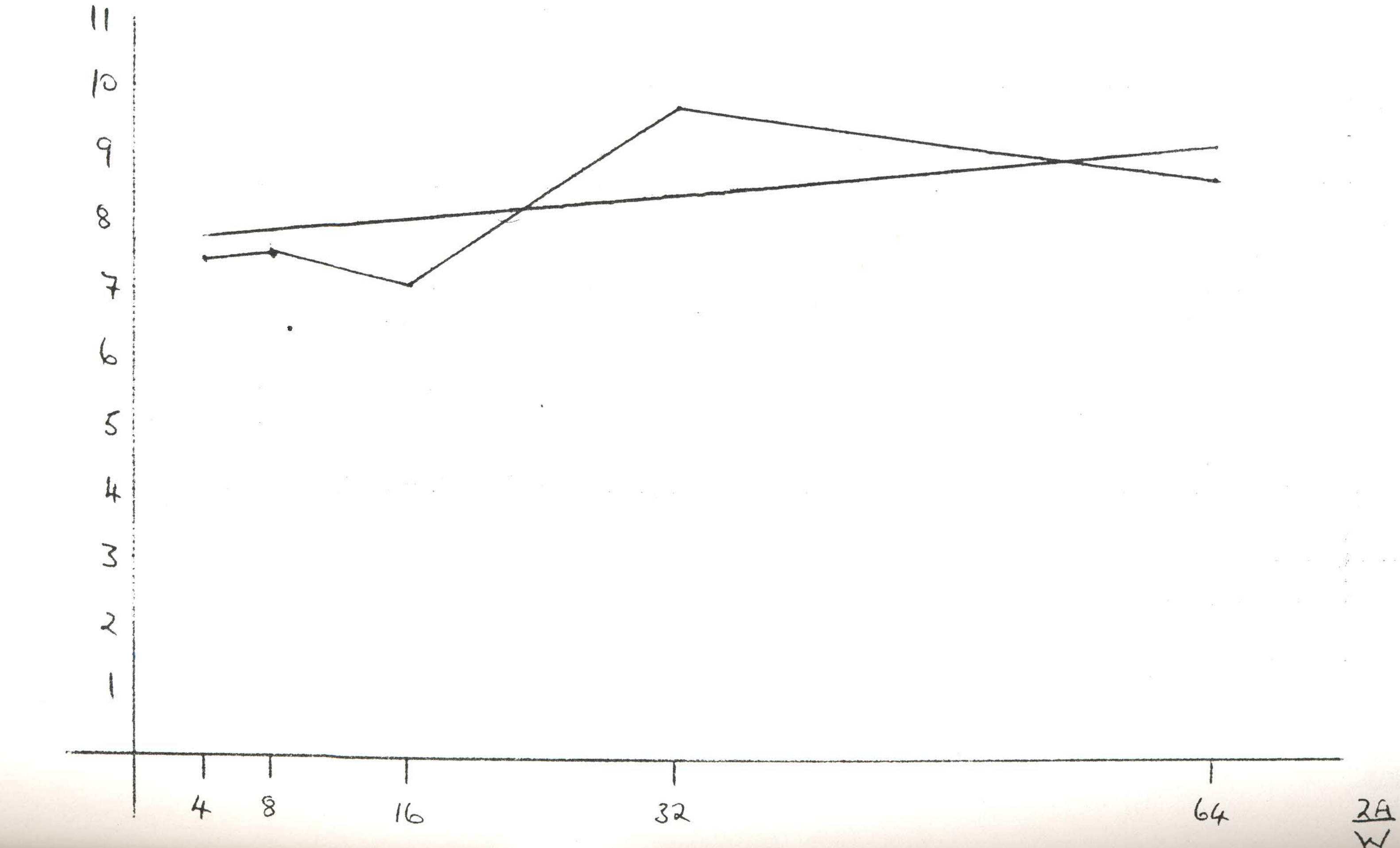



Seconds
SUBJECT 5 ♂
11
10
9
8
7
6
5
4
3
2
1
4
8
16
32
64
2A/W

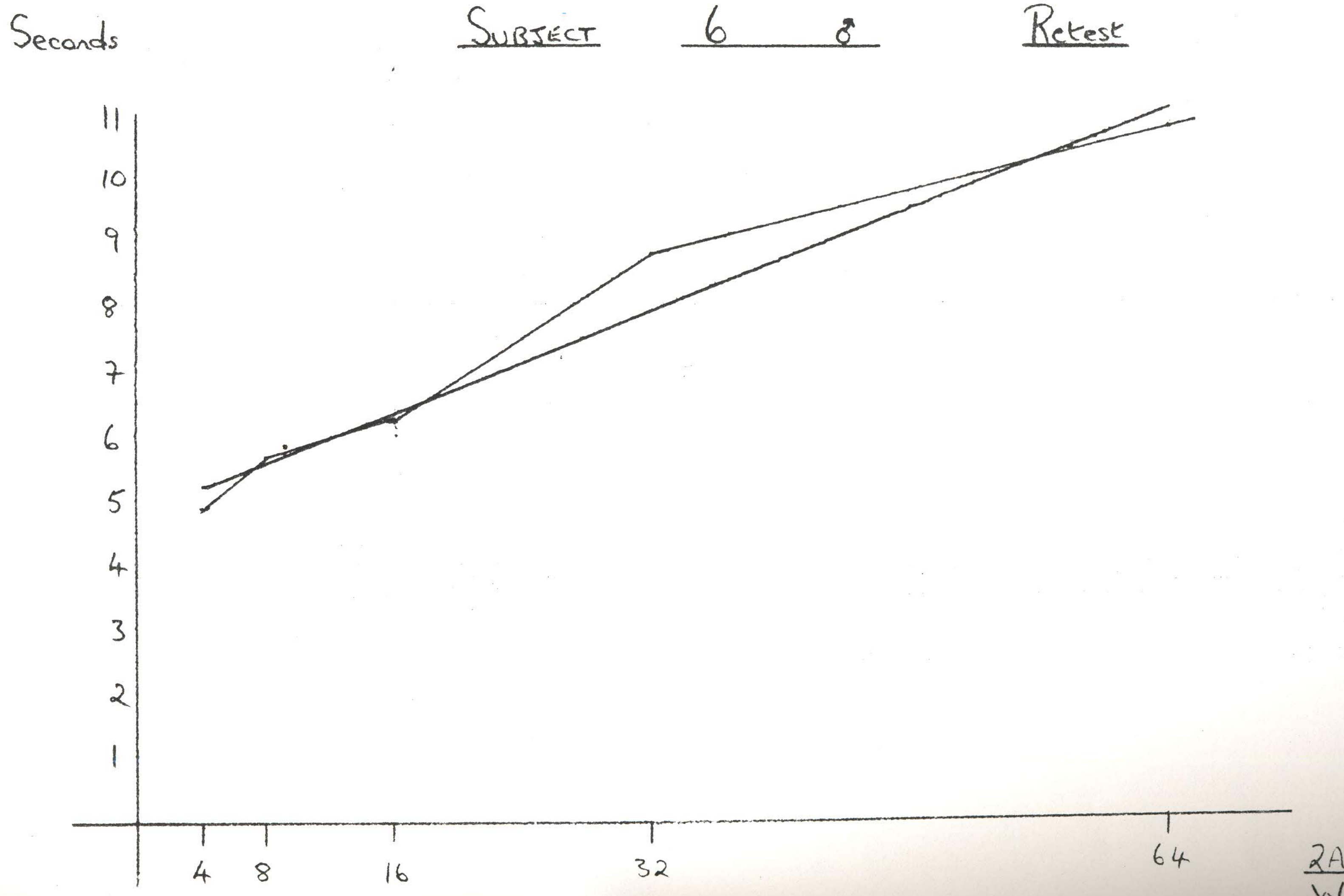
Subject 5 ♂ Retest



SUBJECT 6 ♂



Subject 6 ♂ Retest



3(c) Two ID "16" were chosen and it was of some interest to test if the difference between the two was of any significance.

Results

ID "16" 1 (A = 4", W = ½")	ID "16" 2 (A = 2", W = ¼")
9.40	7.83
9.92	10.16
6.41	6.27
7.91	7.31
6.24	6.56
8.16	7.58

To test for any significant difference between the results obtained the matched pairs t score technique was used.

x_1	x_2	d	d^2
9.40	7.83	1.57	2.4649
9.92	10.16	-0.24	0.0576
6.41	6.27	0.14	0.0196
7.91	7.31	0.60	0.36
6.24	6.56	-0.30	0.09
8.16	7.58	0.58	0.3364
$\bar{x}_1$=8.007	$\bar{x}_2$=7.618	d=2.35	d^2=3.3285

Using the formula :

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\frac{{}^1d^2}{n(n-1)}}$$

$$ {}^1d^2 = d^2 - \frac{(d)^2}{n}$$

$$= 3.3285 - \frac{(2.35)^2}{6}$$

$$= 3.3285 - 0.92$$

$$= \underline{2.41}$$

$$t = \frac{8.007 - 7.618}{\frac{2.41}{6(6-1)}}$$

$$= \frac{0.399}{0.283}$$

4(a) Discussion of Results

The thesis put forward by (Fitts 1954) suggests that a linear relationship exists between time and "ID". Additionally he suggests that with an increase in ID there should be an increase in time.

Subject I

The time for "ID" 16 for this subject was longer than expected when compared with the line of best fit. (The blue line on graph paper). However the time for "ID" 32 was predictable to a fairly high degree of accuracy. Further inspection of the actual tapping sheet on which the subject was tested revealed that the subject made no marks outside the target areas which suggests that he was concentrating on accuracy more than on speed.

Subject 2

This subject's graphical representation of times plotted against "ID" is almost linear suggesting that he was concentrating on both speed and accuracy, except for ID 4 and 16 in which it can be tentatively suggested that he concentrated slightly more on speed in the former and accuracy in the latter.

Subject 3

Again here a linear relationship seems to exist between ID and time. The score deviates only slightly from the line of best fit.

Subject 4

Here the scores and the line of best fit almost coincide. Prediction of ID 32 was very accurate (see graph).

Subject 5

Inspection of the graph of this subject reveals an inconsistent pattern. The slope of the line of best fit indicates that this subject was concentrating more on speed than accuracy. Further inspection of the actual tapping paper reveals that the pencil marks were very inaccurate.

Subject 6

Although the line of best fit slopes to an increase in time taken with an increase in ID there are some instances where the subject would seem to have concentrated more on accuracy than speed and vice versa. The subject's time for ID 64 is one second less than for ID32. This suggests an increased concentration in accuracy for ID 32 and it is borne out by checking back on the tapping paper where for ID 64 there are no pencil marks at all in the right hand target, but there are significant improvements in accuracy in ID 32.

On the basis of the results that have been obtained it would appear that the concept of channel capacity put forward by Fitts op-cit can largely be supported. However there are two cases which seem worthy of a re-test, i.e. subjects 5 and 6.

4(b) Re-Test

Following on from the inconsistencies obtained in the results, compared by the thesis put forward by Fitts op-cit, it seems pertinent that a retest should be made. Since subjects 1-4 seemed to follow Fitts thesis, only subjects 5 and 6, who did not seem to follow Fitts thesis, were reteste

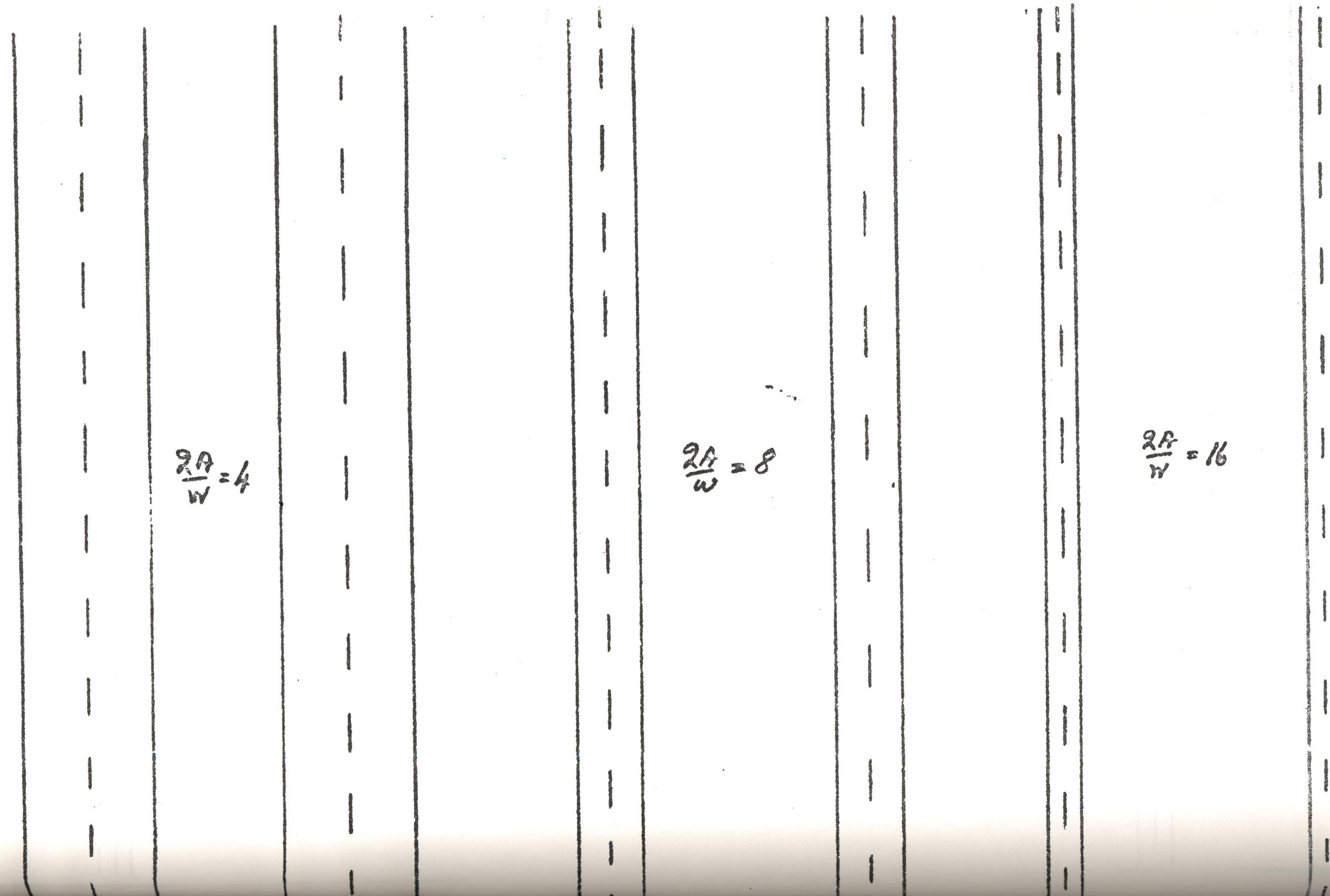
The same experimental procedures were followed as before except that the subjects were retested on their own. It was felt that the retested subjects lacked social facilitation which seemed evident during the original testing.

On retest, both subjects 5 and 6 showed a more consistent pattern, i.e. the lines of best fit indicated an increase in time with an increase in ID. The results obtained from subject 5, even on retest were still deviating more than others.

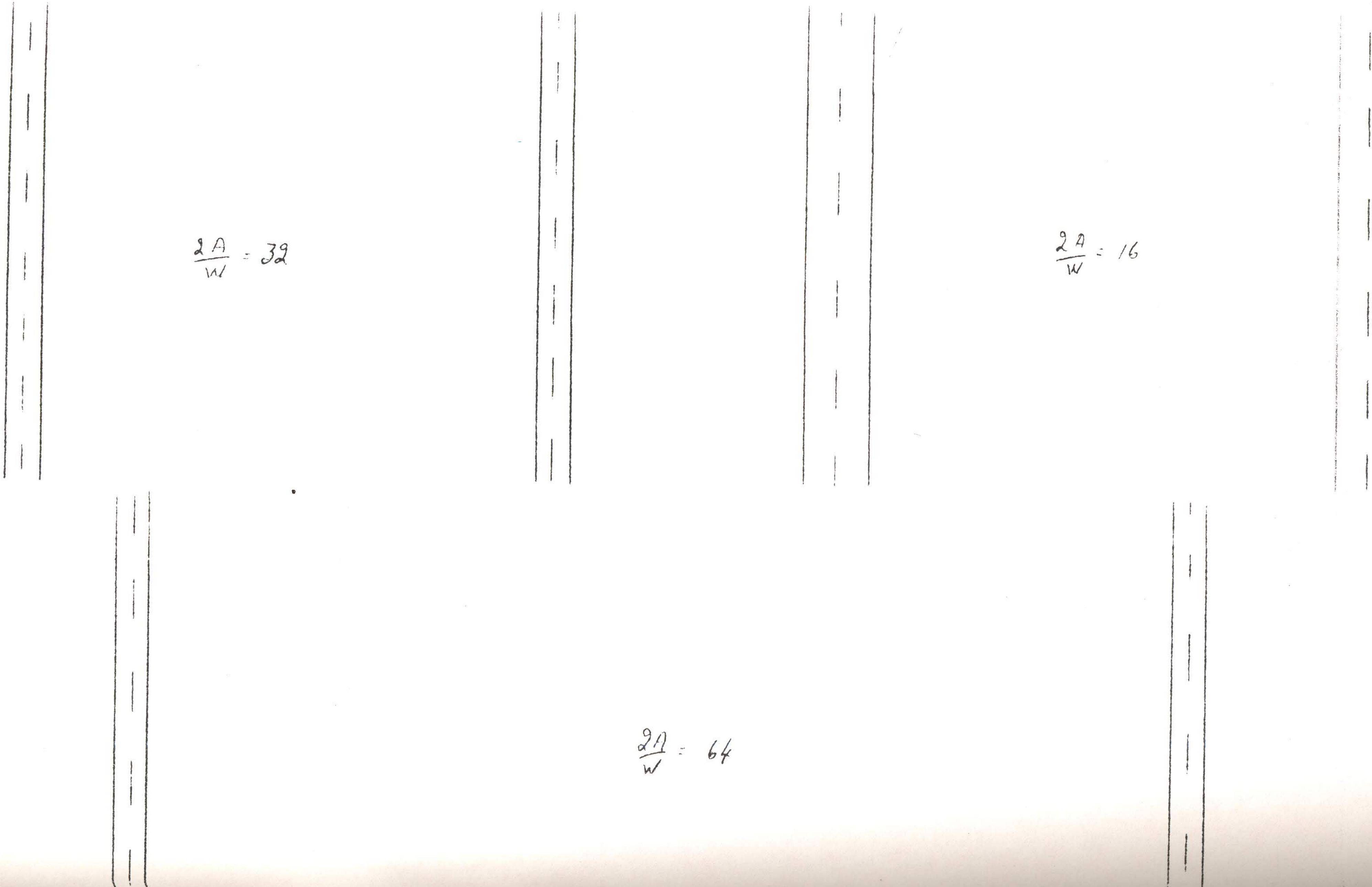
5. Concluding Remarks

(1) Discussions on this experiment refer to the feasibility of the achievement of speed and accuracy at the same time. It does seem that with an increase in speed, accuracy suffers, and with greater concentration on accuracy speed decreases.

(2) One major problem seems to be that it is difficult for the subjects to understand what the experimenter was looking for. Therefore, the task set had no real meaning for them and there was no incentive value for doing the task. It was noted that the subjects (children) tended to do the task to please the experimenters (their teacher and a visitor) because there was no other incentive.



$\frac{2A}{w} = 4$
$\frac{2A}{w} = 8$
$\frac{2A}{w} = 16$



$\frac{2A}{W} = 32$
$\frac{2A}{W} = 16$
$\frac{2A}{W} = 64$