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Eye speed, motility and athletic potential

"The eyes are a window on the soul, but the extraocular muscles animate them and their exquisite motor nerve control reflects every thought and emotion"

It is easy to understand why evolution invested so much cortical space in vision and its control – seeing things was the easiest way to avoid being eaten. The speed and precision of the extraocular muscles is unsurpassed anywhere else in the body[1,2].

The ratio of motor neurones to muscle fibres in the extraocular muscles can be as low as 1:1, compared with calf muscle, where there may be as many as 2000 synapses from each motor nerve[3].

In modern sport, downhill skiers travelling at speeds of up to 80mph and ice hockey players trying to hit a small dangerous puck, develop eye speed to almost superhuman levels[4].

Athletic ability and visual performance

It is not surprising that a number of measures of visual performance show a high correlation to athletic ability[5,6,7,8]. In young footballers visual performance is correlated with their coaches assessment of playing skill[9].

Whether the game is fast moving like ice hockey or slower and more thoughtful like curling, it is likely to be an advantage if the athlete has good oculo-motor control and cognitive ability. It appears that fast eyes and fast sports go together. It would be interesting to know if this is true and if the speed of the extraocular muscles predisposes individuals to certain sports.

Figure 1
Accommodation Vergence Facility
(By courtesy of Bausch & Lomb)

The attraction of being able to measure the speed of the eyes is that physiologically eye muscles are the same as leg muscles and the physio-chemical responses underlying their activity are similar[2]. The problem with making comparative measurements in thigh muscles, for example, is that performance is affected by training, high repetitions, which could increase the accuracy of the measurement, can cause rapid fatiguing even in trained athletes.

The extraocular muscles are under the same hormonal influence as the other skeletal muscles, but they are isolated from the external rigours of training and normal physical development.

The similarity of the extraocular muscles to other skeletal muscles is disguised by their size and function. In fact, skeletal muscle is very adaptable. One extreme example of the conversion of one muscle type to another is cardio myoplasty, where the shoulder muscle is wrapped around a defective heart.
A pacemaker then makes it contract repeatedly. With time it changes from a relatively fast twitch muscle to slow twitch with high oxidative fibres, capable of sustaining the heart without fatigue[10]. It may be that all muscles have the potential to become like all others if they are required to do a specific job[11].

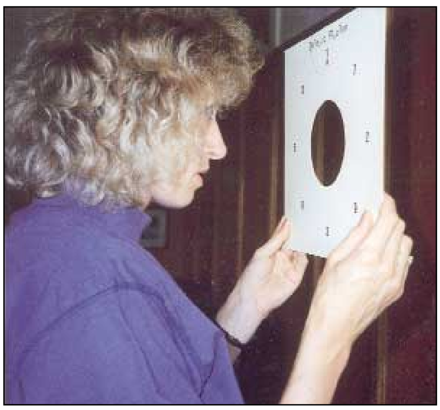
It is proposed that the extraocular muscles would be a better comparative measure than (any) other skeletal muscle. The possibility exists that, supported by the eyes' ability to fixate on measuring points, they could be used to measure innate muscle speed and so predict athletic potential.

Measurement of eye speed

One of the measures of eye speed which has shown a correlation to athletic ability is the Hart Test[12], otherwise known as Accommodation Vergence Facility or the Distance Rock Test (**Figure 1**).

It measures the speed at which a subject can look from a line of letters on a hand-held chart to a similar line at six metres and back again to the next letter in the sequence. To do this well, the eyes need to move quickly from distance to near for a period of 30 seconds or more.

Figure 2
Dianne Davis, GB high jump record holder



The test is quite difficult and it may be that cognitive elements like programming of saccades, visual memory (position and name of letters already read), retinal blur, acuity and accommodation will also affect the results. This could be the reason why this test does not differentiate between ability in fast explosive sports and sports which require more control[5].

One possibility would be to reduce the need for thought and mental agility in the Hart Test to increase the emphasis on muscle speed. In other words, make the speed of the extraocular muscles the most significant contributory part of the time taken, by using for example:

- An increased range of eye movement[13] (motility as well as vergence)
- Symmetry of eye movement about the primary position[13]
- Easily remembered target positions[14] (reduced saccade programming time)
- Non accommodative large targets low acuity demand[15] (number recognised without accommodation delay)
- Numbers rather letters[16] (need for visual memory reduced)
- Test well practised before data taken (reduced thinking time)

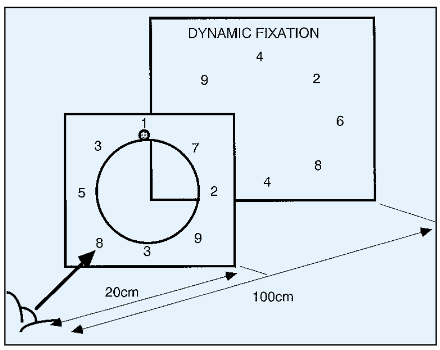
In this way the eyes would be kept moving as much and as fast as possible with brief fixations used only as measuring points. This adaptation of the Hart Test could be called, for convenience, Dynamic Fixation (**Figure 2**)

Dynamic fixation (DFT)[17]

In DFT, the subject is timed for 24 vergence and motility cycles using a distance (1m) and near chart (**Figure 3**).

The subject holds the near card so that all the numbers on the distance card can be seen with both eyes through the middle of the near

Figure 3
The Dynamic Fixation Chart



Test	Original Data	Time for one cycle (secs)
Accommodative Vergence Facility	15.75 cycles in 30 secs	1.90
Dynamic fixation	24 cycles in 17.64 secs	0.74

Table 1
Pilot study comparative times

Group	Average age
International	26.63
Recreation	26.67
Archers	21.64

Table 2
Average ages of the subjects

card without moving the head or card, this is designed to occur at about 20cm.

After practising, the subject is asked to read the numbers out, starting with the one on the near chart and then going to the four on the distance chart and back to the seven at near and so on, in a clockwise direction.

The time is taken for three circuits (24 cycles), starting when the subject says "one" for the first time and finishing when they say "one" for the fourth time. After recording this result, two more readings are taken.

Pilot study

A pilot study showed that the near far cycle times for Dynamic Fixation were 2.5 times faster, even in non-athletic subjects than the times for Olympic athletes on the Hart Test (**Table 1**). If it is assumed that the speed of a saccade is constant for an individual, the increased speed must be due to a reduction in the cognitive elements involved in eye movement. This would make DFT a better measure of the speed of the extraocular muscles than the Hart Test.

Hypothesis and subjects

To test the hypothesis that DFT is able to measure differences in eye speed, two groups of athletes were chosen from opposite ends of the physiological spectrum. The aim was to see if the two groups had different eye speeds and if the faster eyes belonged to the group in the more dynamic sport.

The subjects were 16 international track and field athletes, 13 international archers and 18 controls (otherwise healthy people who did sport for recreation).

Subjects

- International
  – Track and field athletes (dynamic, explosive sport)
- Archery – The British National Archery Squad (non dynamic, control sport)
- Recreation
  – A group of physically active but non-competitive students of a similar age to the other subjects

Figure 4
Data sheet

Time (24 cycles)			
1	2	3	Mean

Table 3
Results – international subjects

Initials	Sex	Age	Event	Time 1	Time 2	Time 3	Mean	
pd	M	31	1500m	16.09	15.18	14.17	15.15	
ac	M	28	100m	14.49	14.40	12.77	13.89	
sb	F	21	800m	14.44	12.25	12.49	13.06	
sd	F	26	3000m	15.93	14.94	14.25	15.04	
hcf	F	26	1500m	14.43	13.11	12.60	13.38	
ms	M	35	1500m	15.90	14.62	15.06	15.19	
dm	M	27	discus	16.66	14.47	14.01	15.05	
gl	M	24	1500m	14.88	14.27	14.00	14.38	
nd	M	30	110m H	16.40	16.07	15.50	15.99	
cb	M	22	110m H	23.94	20.01	20.95	21.63	
ad	F	23	800m	22.09	20.69	18.24	20.34	
dd	F	33	high jump	17.67	15.47	14.23	15.79	
dl	M	28	3000 S/C	11.78	10.66	9.94	10.79	
ac	M	29	1500m	24.37	21.37	20.37	22.04	
aj	F	25	1500m	16.25	16.64	14.93	15.94	
ch	M	18	high jump	18.73	15.72	14.50	16.32	
			Means	17.13	15.62	14.88	15.81 3.05	Mean St Dev

Group	Sample Male/Female	Age	Times Mean	Times St Dev
International N = 16	M10, F6	26.63	15.81	3.05
Recreation N = 19	M13, F6	26.67	18.68	4.31
Archers N = 13	M9, F4	21.64	18.20	3.76

Table 4 Summary of results

Age

Age was important because of the possibility of reducing extraocular muscle performance and loss of accommodation. All subjects were within presbyopia with the possible exception of one archer. The ages of the international and control subjects matched well. The archers were, however, five years younger on average (**Table 2**).

Data collection (Summer 95)

The data was collected where the subjects lived or participated in their sports. For the internationals this was at the pavilion at the Loughborough University between 5 and 7pm British Summer time. For the archers, this was in a spacious meeting room adjacent to the indoor shooting hall at the Lilleshall National Sports Centre during daylight hours.

The recreation subjects were tested in various rooms and locations, the two main ones being the dimly lit corridor of a hall of residence before sunset and at different times of day and in the 1st floor reception area of a high street optometric practice. The estimated variation of illuminance level was between 100 and 500 Lux.

Variable illumination

It is hoped that the low acuity demand of DFT reduces the effect of variable illumination. One of the reasons this was built into the design was to allow it to be used on site, where there is often little control over lighting conditions.

Recording results

After each set, the time was recorded immediately on a data sheet (**Figure 4**) and the second set started as soon as this was done. The interval between the readings was standardised in this way. In what could be a partially anaerobic exercise for the extraocular muscles, recovery time was important and kept consistent.

Group	Average times 1	2	3
International	17.13	15.62	14.88
Recreation	20.28	18.27	17.48
Archers	19.07	17.95	17.41

Table 5
Averages of the three readings by group

Name	Sex	Age	Event	Reading 1	2	3	Mean	St Dev
cc	F	34	pentathalon	37.49	29.89	26.72	31.37	5.53
gm	M	30	football	52.23	26.61	26.65	35.16	14.78

Table 6 Extracted data

	Recreational Vs International				Int Vs Archer
	Readings				
Nº	1	2	3	Mean	Third reading
P	0.0295	0.0193	0.0099	0.0176	0.025

Table 7 Summary of probabilities

Results

The results were tabulated for the three groups as shown in the example for the internationals (**Table 3**).

The summary of the results for the groups is shown in **Table 4**. **Table 5** shows the average for each of the three readings by group.

Occasionally completely anomalous times were found – these were extracted from the data to prevent distortion of the results (**Table 6**).

Analysis (Students T-test)

Various probabilities were calculated (**Table 7**). Samples compared included the international and recreation group for each of the three readings and the mean, internationals and archers using the third reading only.

A probability of 1 means that both samples are from the same population and there is no difference between them. A probability of 0 means they are from different populations. To be statistically significant, the probability must be less than 0.05 (5%).

Discussion

The learning curve

One concern was that during a fairly thorough familiarisation with the test, the sequence of numbers was learnt and the time taken was nothing more that the speed of articulation. This is unlikely because even though the test cannot eliminate cognition completely:

- The fastest time recorded was, exceptionally, just under 10 seconds. It is possible to read the sequence in a straight line in nine seconds even without memorising the numbers, so the movement of the eyes is likely to be the limiting factor, not the speed of articulation (with certain exceptions discussed later)
- DFT uses a random sequence of numbers which are difficult to memorise in three minutes while other aspects of the test are being taught
- Partial learning of the shape and sound of the number and its order in the sequence is part of the process of reducing thinking time. In practice, it was quicker to look at the number and to say it, than to try and remember what was coming next
- The subjects were instructed to look at the numbers in turn. Observations of their eye movement and the author's familiarity with the sequence confirmed that this was happening
- If the subjects assumed, even subconsciously, that the next number say, had been memorised it often lead to missing it out or saying it incorrectly. This actually slowed the time as they became aware of the mistake. In other words as they started thinking, "I've said the wrong number," or "I have not followed instructions". Once the subjects started retracing their steps, the result became meaningless and it was put down as part of the learning curve. The reading was then repeated. This could have affected the final mean of the three readings, but it was thought the error would be less than if the faulty time were recorded, especially if the protocol was applied equally to both groups and the control

Difference between the readings

The average time for the third reading in all the groups is almost invariably faster than the second, which is faster than the first, so it seems likely that the readings 1, 2, and 3 are measurements of the subjects at different points on a learning curve. When a reading was slower than its predecessor, it meant that the subject was trying too hard and making mistakes. In hindsight, these readings should have been repeated but their infrequency (once or twice) should not affect the overall conclusions.

The object of Dynamic Fixation is to measure muscle speed when the test is thoroughly learnt and understood and thinking time is reduced to a minimum. This point is not exactly known, because only three readings were taken, but it is more likely to be nearer to the third reading than the first. The most significant reading in recreation versus international is the third reading (p=0.0099).

It is possible that the increasing significance is because the internationals learned the test quicker, but if memory played a part in reducing times, it is likely to have affected both groups equally since their mix of age and educational background was similar.

The more likely explanation is that the test was learned at roughly the same rate in the two groups and that as the cognitive element reduced the effect, the difference in muscle speeds increased. The results were in any case significant for all three readings. This supports the hypothesis that muscle speed is being measured by DFT and that the third reading is when the test result is at its most reliable.

On this basis, taking the third reading for international and archer subjects the result is also significant (p=0.025). Again when comparing the internationals and archers memory differences would be difficult to explain in two groups of similar age, who both have the native intelligence to be at the top of their individual sports.

There was no significant difference between the archers and the recreational control group (p=0.953 by analysis of variance). As far as muscle speed is concerned, these two groups probably come from the same population. It would be interesting to apply the Hart Test to them to see if, as predicted, the cognitive abilities of the archers distinguishes them from the control group. The residual cognitive elements could be the reason why there was slightly less significance in the archer/international result.

The effect age

It is likely that muscle speed decreases with age and certain that accommodation does. Both factors are likely to contribute to slower times. The archers were five years younger on average than the international group but still had slower times. This increases the confidence that the difference between the groups is real and due to innate muscle speed.

Exceptions

Occasionally, otherwise gifted athletes had unusually slow times. Two of the athletes had exceptional ability in visually difficult events (**Table 8** – cc ranked number one in Britain in the heptathlon, and gm, a former professional soccer player).

The relationship between the extraocular muscles and the visual demands of these two sports, makes it reasonable to assume that the performance of these two athletes was not due to slow eye speed. It appears that these times were not measuring extraocular

Name	Times	
	Own	Group
cc	31.37	15.87
gm	35.16	16.33

Table 8 Times for excluded subjects

muscle speed but some deficit in central processing. Later research suggests that this could be connected with learning difficulties and dyslexia[18].

Nature and nurture

If Dynamic Fixation is showing that the two groups tested have different eye speed, the question still remains is this innate, or is it because of participation in their particular events? Although it is argued that the extraocular muscles are isolated from the rigours of athletic training, the visual demands of the event could also have an effect, as it appears with downhill skiers.

Perhaps the best answer to this would be a longitudinal study of a group of non-specialised youngsters to see if predictions of sporting preference are correct. The difficulty is that elite groups, like the ones tested, make up a very small part of the general population. In a group of randomly chosen youngsters, it is unlikely that many will go on to be international athletes, making the scale of such as study in terms of numbers and time, impractical.

Another problem would be at what age to start the study – signs of ability can appear in 12 and 13 year olds[8] and anecdotally even younger. This begs the question, why some children show unusual ability? More generally, why are we all good at some things and not so good at others? There is no incentive or satisfaction in doing things which we are bad at (even though human perversity will sometimes buck the trend) and it is possible that a predisposition for certain activities is influenced by innate ability.

Perhaps the strongest argument, in the context of this research, that DFT measures an innate difference between the groups, is the visual demands of the two sports considered. It is easy to understand why downhill skiers develop such fast eyes, but more difficult in athletics. Television pictures of Linford Christie usually show him staring fixedly ahead, his ability to compete does not seem to depend on eye movement at all. Archers on the other hand repeatedly re-fixate on the gold at the centre of the target and the foresight on the bow. It could be argued that the archers should have the faster eyes if eye speed were purely environmental (nurture).

Conclusion

Allowing for the exceptions, the probability is that the archers and internationals did have significant differences in muscle speed and that the faster eyes belonged to the subjects in the explosive event (international track and field athletics). On this basis, the hypothesis, is accepted.

If, as is argued, this is due to innate physiological differences between the groups it is cautiously concluded that the extraocular muscles give a measure of innate speed. Given the visual characteristics of explosive and control sports established by this research, Dynamic Fixation may be useful in predicting athletic preference and ability.

The Dynamic Fixation Test is available through Lafayette Instrument Europe, Park Road, Sileby, Loughborough Leicestershire LE12 7TJ. Telephone 01509-817700.

About the author

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Figure 5 Fatigue can effect results

Figure 6 Archery is a control sport