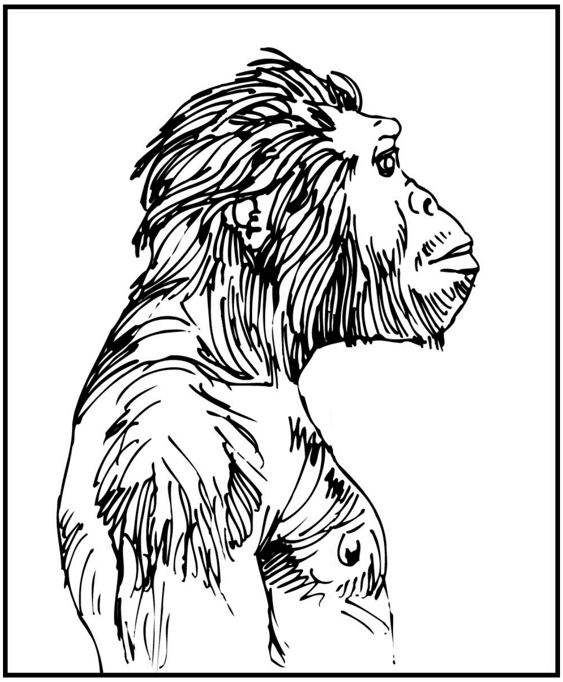
‘Lucy’ and the ‘Arc of Visual Perception’



Introduction

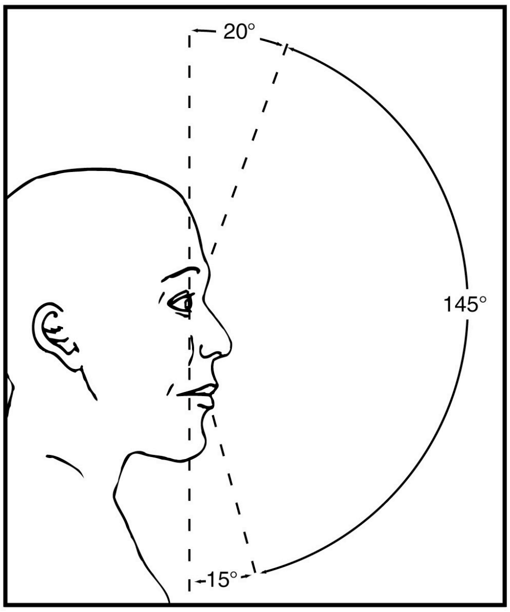
It is now generally believed that our primate ancestors living over three million years ago walked upright. The main factors that have influenced this belief are the discovery of the ‘Lucy’ fossils at Afar in Ethiopia, together with a set of footprints in hardened volcanic ash in Laetoli in Tanzania. Both of these have been dated as coming from a similar period of between 3 and 4 million years ago. Studies of these and other fossils have been interpreted as showing that a fully upright, bipedal locomotion was practised by primates at this time, leading further to the suggestion that these primates lived by foraging, hunting and scavenging on the open Savannah. After the discovery at Afar these fossil remains were identified as being a separate species and named Australopithecus Afarensis and were suggested as being from our ancestral line.

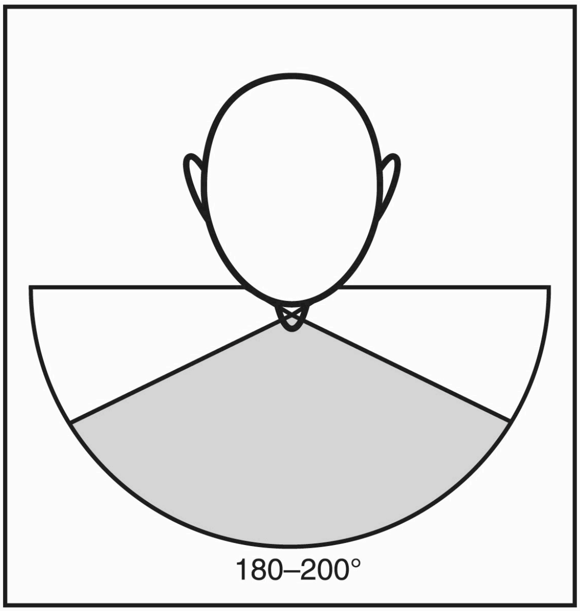
There is however one fundamentally simple, but vitally important, characteristic that I believe has not been considered in presenting this creature as having a permanent upright posture. This is the visual ‘arc of perception’.

Of all the senses vision is by far the most important, commanding 70% of all the sensory receptors of the human body. It is the main source of information from the external environment and it is suggested that 90% of the information stored in the brain is of visual origin. It is therefore the main influence in our relationship with the natural world in controlling our actions in it and our reactions to it.
As with all our senses and capabilities this has developed for good reason. Nature, through the process of Natural Selection, does not waste resources creating an ability that is not utilised to the full at some stage. The development of this sense therefore has had a significant influence on the adaptation of man to the natural environment and consequently on the evolutionary progression to modern man.

The Arc of Visual Perception

In humans the clear focus of the eyes is a cone of a few degrees in width. However the total ‘cone’ of visual perception is, in most people, very wide. This cone of perception, or rather the combined cones of each eye, covers a total arc of 180 - 200 in a horizontal plane and up to about 145 in the vertical plane (see Diagrams below). This ‘cone’ of visual perception is the total external area from which rays of light are received, through the cornea and the lens, by the retina of the eye.





To demonstrate the wide horizontal arc of perception, consider a person standing in the middle of the halfway line of an empty football field focusing his eyes straight ahead at the goal posts. If a second person on the sideline to his right or left, say 50 metres away, walks from a position behind him and moves into a position on the halfway line, at about 90 to his line of vision. The eye of the first person will then detect this movement. In other words, while the focus of the eyes is at right angles to this image, the brain has received a visual signal through the eyes and is aware of the incursion into this space.
The natural instinct would then be to turn and focus on this perceived movement to establish what this object is and whether it is a potential danger or otherwise worthy of interest.

The total vertical arc of vision is not as large as the horizontal arc, the upper periphery being restricted by the eyelids and lashes and the eyebrows, and the lower to a lesser extent by the cheekbones. This normal vertical arc of visual perception, with the eyes at horizontal focus, includes the surface of the ground from about half a metre ahead, or about one walking pace.

As with all our abilities this visual ability, or sensitivity, has evolved to this extent for a reason. For example if out walking in easy, flat natural terrain, we become aware of an obstruction 20 or so metres ahead, right in our chosen path, such as a small rock. Our eyes focus on this object momentarily, and the fact that this is in our path and is a potential danger is mentally registered. This is normally done quite unconsciously. Once this potential danger is noted, we no longer need to keep our eyes focused on this object alone as our brain has worked out roughly how many steps it will take us to reach it. Our brain via our visual senses maintains an indirect 'watch' on this object and reminds us when nearing it, to refocus on it, if necessary. Then, again if it is necessary, it reprograms the co-ordinates and adjusts our pace or direction to avoid stepping on it.

In other words through the visual cortex the brain can track any object within the wide arc of perception of the eyes, without having the eyes focus directly on it. If it has been noted to be of interest in some way then a mental 'watch' is kept on this object and, when time or circumstance permits, the focus may be returned to check up on it. While such an object may not be in focus, it is however still visible right up to the periphery of the cone of visual perception, or up to the point where no light from it reaches the eye.
An obstacle such as the rock on the ground in our path is sensed by the eye and the image of it monitored by the brain, without it being in the main area of focus of the eyes, right up to the point where we would actually step on it.

Vision and Co-ordination

When we are in motion the sense of vision is by far the most influential source of external information for the co-ordinational processes leading to any actual movement.
Co-ordination, with particular reference to human locomotion, I will here define as the process of the movement of the limbs and the body initiated by the contraction or relaxation of various muscles, responding to signals sent by the brain, itself reacting to external stimuli received by the senses and also, as discussed later, some internal stimuli. In other words the sequence of sensory stimulation, to mental analysis and reaction, on to physical reactions, or movement.

When in motion we unconsciously make numerous, simultaneous co-ordinational decisions, and often change them as quickly due to circumstance, amongst many other things as to actual placement of the feet. These actions may result from the innumerable visual and other sensory stimuli reaching the brain from all parts of the body and the brain is continually assessing this information and either immediately acting on it or storing it or ignoring it.

With respect to the visual senses, continuous light images stimulate the retina of the eye, which refines these and signals on to the visual part of the sensory cortex. Computation and assessment by the brain of any relevant sensory information then takes place. When moving, decisions made are then passed on as instructions to the motor cortex and thence via the spinal cord to the motor neurons activating the relevant muscles of the body involved in the programmed movement.

Most physically fit and well co-ordinated people are able to avoid an obstacle, such as the rock mentioned earlier, completely unconsciously and automatically. Those people with poorly trained co-ordination or subnormal eyesight may need to refocus on such a simple, small object or feature, perhaps more than once, and in particular when it is very close. On the other hand those with well trained co-ordination skills such as Cross Country Runners or Orienteers who are used to running in these circumstances are able to automatically adjust pace and/or direction to avoid such an obstacle without at any time refocusing on it.

Vision and Foot Placement Programming

When in motion a bipedal human is continually viewing the ground surface ahead and unconsciously programming the placement of feet some distance ahead. Of course in the modern urban environment most surfaces are manufactured to be as secure, even and flat as possible so that it is possible to walk in many situations without taking much notice of where the feet are to be placed. The visual concentration can accordingly be mainly on other aspects of the local environment through which we move.

When on the move in natural terrain however the concentration and visual focus, for this aspect of locomotion, is dependent on the surface conditions. For example when walking along the coastline there can be beaches of firmly packed flat sand on which it is possible to walk as on a city pavement. Where the foreshore is comprised of, say of a jumble of loose, smooth surfaced stones or pebbles of varying shapes and dimensions of up to 200mm or so, some of which are not firmly positioned and may move when stepped upon, it is a completely different matter.

In this situation it is necessary to visually concentrate on the position of each foot placement and also to feel our way, testing with our feet some rocks which our eyes tell us may be insecurely based. Some poorly co-ordinated, unfit, sedentary people may be fearful of attempting such a traverse while on the other hand some athletes such as Orienteers may be able to run in these conditions.

The maximum potential speed of motion would clearly depend on the conditions and the fitness and the co-ordinational abilities of the individual.
In the first case of firm flat sand it would be possible to run at our maximum individual speed, in the second, for most people, it would be dangerous to proceed other than at a slow walk. The reason for this is the need to concentrate on foot placement immediately ahead.
For those with poor co-ordination such concentration and focus would be on each individual foot placement one by one, coupled with ‘feeling’ for the stability of each stone with the tactile and positional senses of the foot.

For those with well-trained co-ordination, whether walking or running and dependent on the degree of difficulty, the focus would be on foot placement perhaps four to five paces ahead. The brain via the visual cortex programs or co-ordinates such foot placements and for these four or five paces the actual, subsequent positioning of each foot on each stone is not normally visually verified or checked with the full focus of the eyes. These placements are, in these circumstances, of necessity irregular. In other words the locomotion may be by means of a sequence of short steps, leaps, skips etc., all possibly involving deviations to the overall course or direction.

This means that this co-ordinated movement of the limbs is planned and pre-programmed into short-term memory. The visual senses utilising the peripheral out of focus vision of the eyes, are monitoring these immediate foot placement positions and adjusting them where necessary.

To examine how this works in a practical sense we can use a simple example of crossing a road. You are on a pavement and decide to cross the road to the other side. Your gaze sweeps across the scene and you assess a route and decide on it. In doing so you absorb a vast amount of visual information, much of which you have not directly focused on, are unconscious of and could not later describe even if you were asked to. Some of this information includes, say, the positions of a lamppost, a parking meter, the kerb, a stormwater drain, the condition of the pavement and the road, parked vehicles, people etc. etc.

Having planned your route, your brain then gives the signals or instructions to activate numerous muscles that result in your walking to the kerb, perhaps changing direction to avoid the meter and lamppost. Then to stepping down onto the road, avoiding the drain and walking over the road in a direction to avoid cars parked on the other side.

Generally, once you have swept the scene visually, you do not need to focus on the obstacles as you come to them. For example you have, unconsciously, noted the position of the kerb in relation to your own position and you have judged its height above the road surface. So in negotiating this particular obstacle you will not normally lower your gaze and focus on it to double-check on these factors. This is partly due to the initial assessment and judgement and partly because they continue to be monitored by your brain via the visual cortex.

This can be demonstrated by the following. While you step towards the kerb and stand on it, your focus is horizontal looking for traffic. In the gutter there is an object that was obscured in your initial visual sweep. While you are stepping onto the edge of the kerb, the object moves. Your attention is immediately drawn to this movement and your instinct makes you look down and focus on this object.

It is clear therefore that, without your being aware of it, your brain is monitoring this area of your total arc of vision.

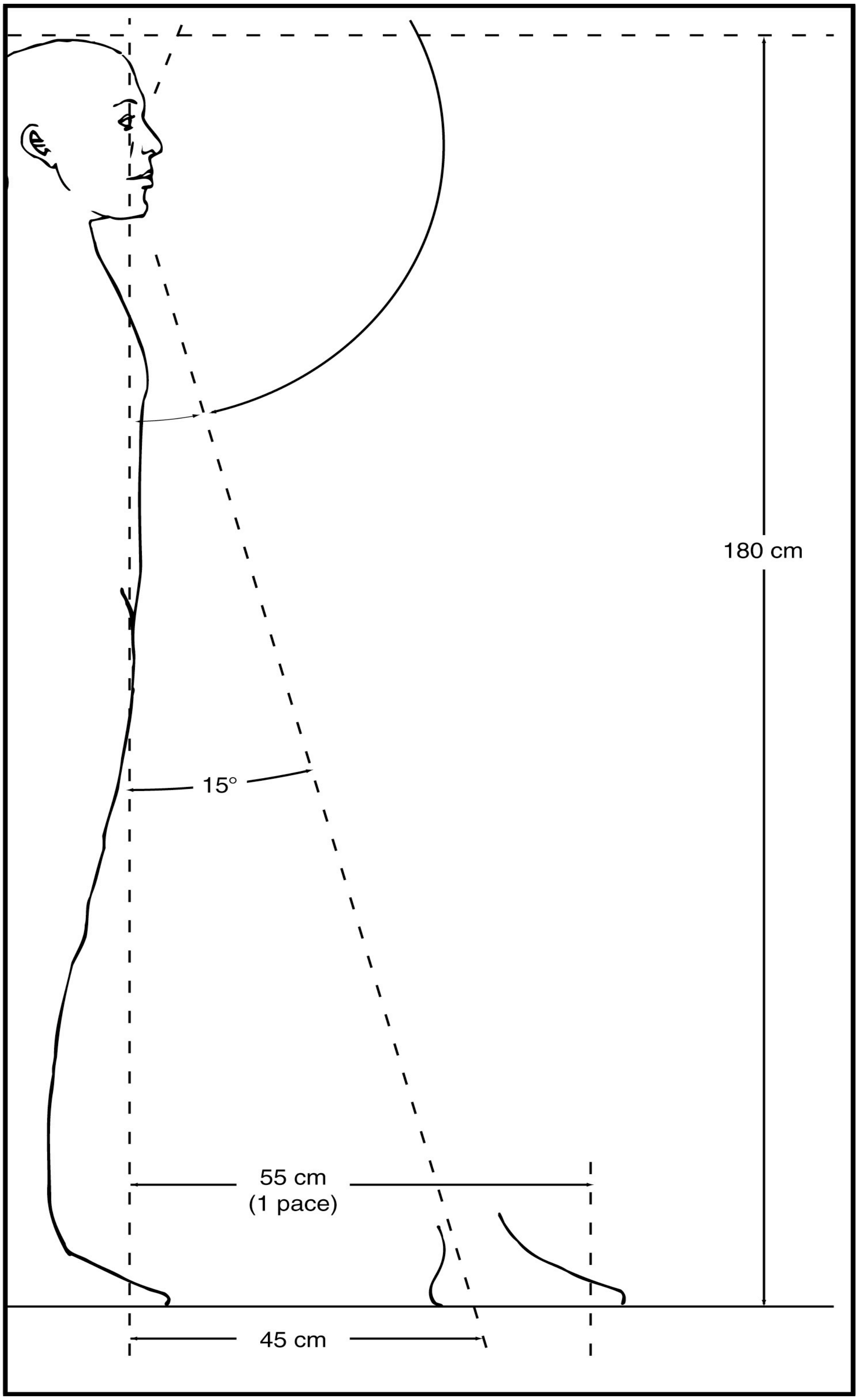
Visual Arc of Perception of A.Afarensis

In his book subsequent to the discovery of the Lucy fossils Donald Johanson shows a profile of what an upright A. Afarensis would look like and life-size models of this are exhibited standing upright in museums, amongst others the American Natural History Museum.

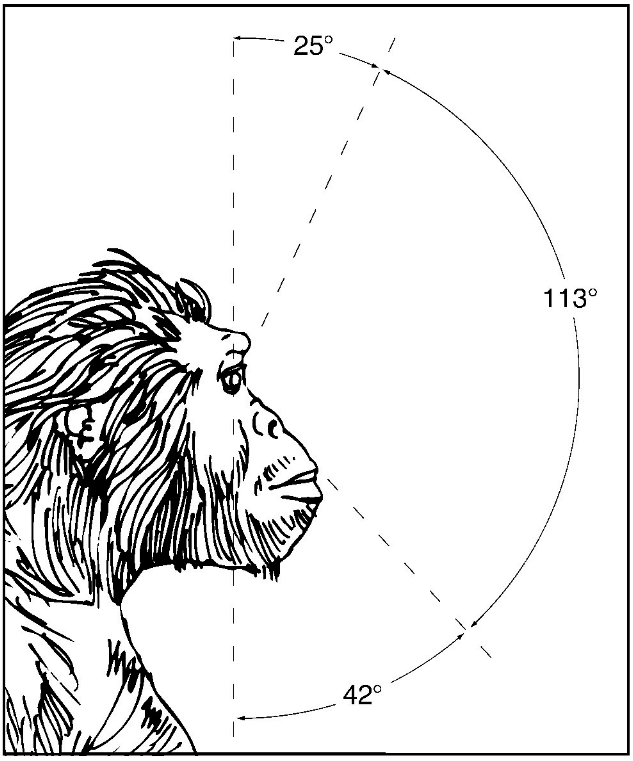
Comparison of the arc of visual perception of this model, or reconstruction of A. Afarensis with that of modern humans shows a significant difference.

If we consider that the facial plane is delineated between the surface of the skull at the centre of the forehead and the surface of the front teeth, (ignoring the projection of the modern human nose). Then modern man has eyes set in the head which at their normal, comfortable inclination are focused at about 90 to the plane of the face. In other words if a modern man is standing upright looking forward in a comfortable stance, his facial plane is vertical to the ground and his eyes focus into the distance in a direction which is parallel to the ground. His vertical ‘arc of visual perception’ includes the ground from about a half metre ahead of his feet. **(See diagram below).**

The Vertical Arc of Visual Perception of Modern Man



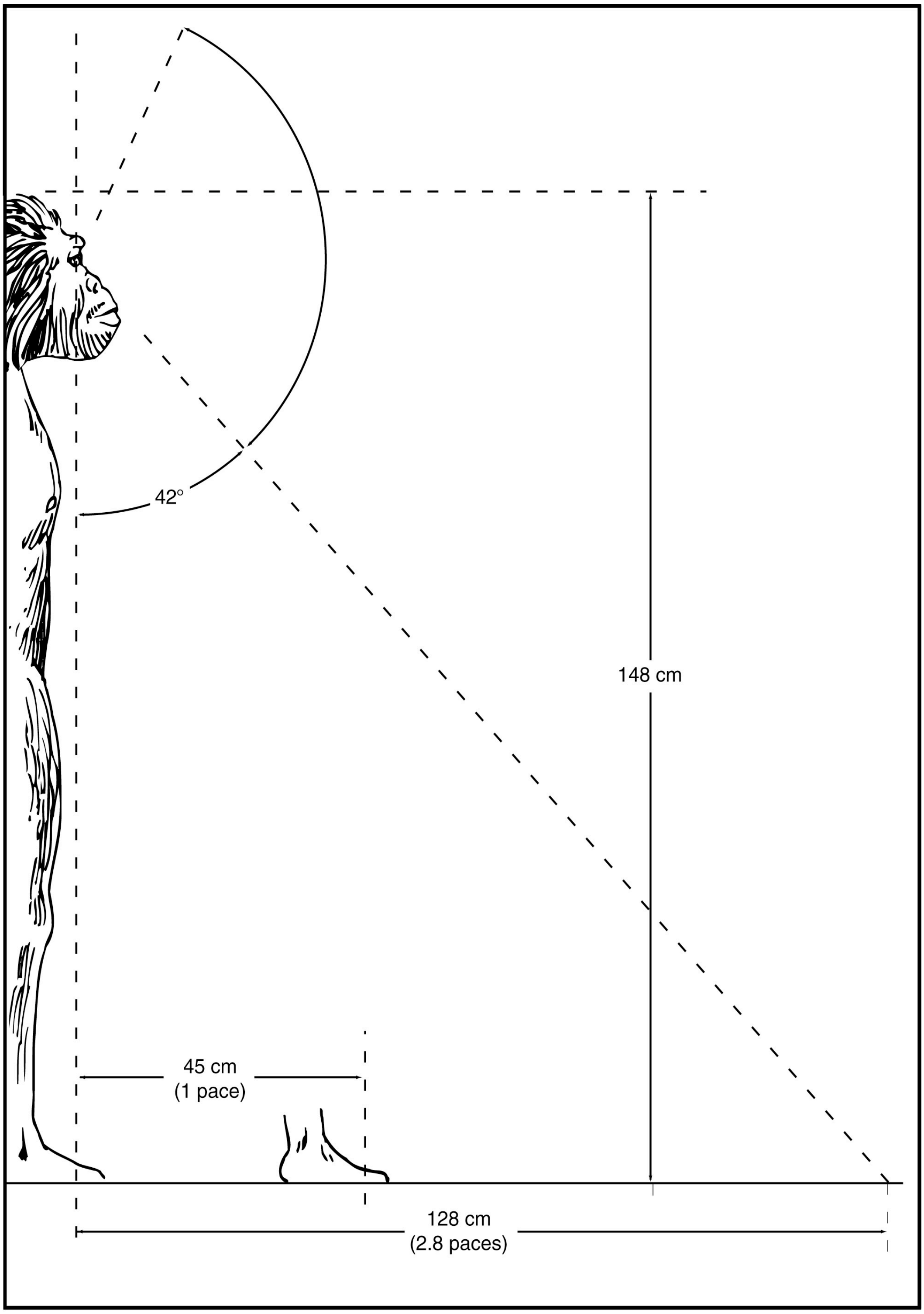
In the A. Afarensis model (**see diagram below**) the eyes are similarly positioned with a focus forward and horizontal to the ground, however facial plane itself is inclined at about 30 to the vertical. In this model the eyes are therefore presented as being focussed at an angle of about 60 to the facial plane. Whilst in this reconstruction the horizontal visual arc of perception would appear to be similar to that of modern man, the total vertical arc appears to be less than 115 .



If this attitude of the head were maintained, the visual arc downwards would be severely restricted due to the width and protrusion of the jaw. Accordingly, if we project a line from the eye downwards past the surface of the nose and jaws. We can calculate that, depending on the height of the creature, the downward vision immediately forward would be restricted so that the ground up to one and a half metres immediately ahead would be out of the vertical visual arc of perception.

Alternatively for A. Afarensis to have it's visual arc covering the ground from about one pace in front of it, it would need to hold it's head so that the attitude of it's facial plane would be as near vertical as possible. It would accordingly have its chin resting on its chest. If the normal stance of A. Afarensis were as depicted then such an abnormal position would have been very uncomfortable to maintain indefinitely. After a few minutes, the strain on the muscles of the neck would be severe, as we can easily test by personal experiment on ourselves. We can therefore only assume that, if A. Afarensis was upright, then the attitude of the head in motion was as depicted and that accordingly it's normal arc of vision did not cover the ground ahead for nearly three full walking paces. **(See diagram below)**

The Vertical Arc of Visual Perception of A.Afarensis



<u>Note:</u> In these diagrams the height of A. Afarensis is taken as the suggested 4' 8" or 1.48 metres for an adult male and that of modern man to be 5' 9" or 1.8 metres. The length of pace of A. Afarensis has been scaled down to 45cm compared to that of a man of 1.8 metres who would have a walking pace of about 50 - 55cm.

Inclining your head backwards so that your facial plane is about 30 to the vertical and walking over a rough and uneven ground surface would give some idea of the effect of this visual restriction. It is clear that such a visual restriction would have a serious effect on the bipedal co-ordination of A.Afarensis in its suggested posture. To examine to what effect this would have had in practice it is necessary to look at the co-ordination of man today for a comparison.

The Senses, Memory and Co-ordination

Of the five senses vision is the main one involved in the co-ordination of movement, and while touch, smell and hearing can also influence movement, taste is not generally involved.
If a sense is recognised by the fact that it receives external signals, then there is in fact a sixth sense, the sense of balance, which is influenced by the force of gravity. This of course is a vital factor controlling movement.

There are however some additional 'internal senses' which have a major role in co-ordination.
One is the mental perception of the position of the limbs relative to the rest of the body, the 'proprioceptive' sense.
A practical example of the use of this would be a gymnast on a single bar attempting a forward somersault. In this exercise without such a positional sense, accurate placement of the feet on the bar would not be possible.

Memory, or experience, also has a direct effect on co-ordination and a simple example of this would be as follows.
When out running in open grassland we observe that the colour of the grass ahead of us changes to a deeper green. Experience tells us that this normally means that the ground there contains more moisture than that at our present position. This visual signal and its stimulation of memory may trigger an automatic reaction of altering course to avoid this potentially difficult area.
This whole process of stimulus, assessment and analysis of both the visual signals and the triggered memory and the subsequent physical reaction may well be done completely unconsciously, while the conscious mind is focusing on other more important matters.

The memory that influences our actions can be from an experience that occurred at any time in our past up to the very short term. This includes memory or experience such as an awareness of our present physical condition and our physical and co-ordinational capabilities.

Co-ordination of Physical Actions and Reactions

When on the move all the external and internal senses referred to plus memory can simultaneously be involved in co-ordination. For instance immediate information from the visual and tactile senses can be combined and referred to balance and experience/memory and result in a physical reaction. These mental processes are therefore highly complex and involved using and connecting different parts of the brain and, as we will see later, are extremely fast. How complex and fast can be demonstrated by looking at a situation faced by an Orienteer running in natural terrain.

Orienteering courses vary in length but these can be 8 to 10 Kilometres or more. Courses are marked out on a specially produced, large scale and detailed contour map. A number of ‘controls’ or markers are set out on the ground at specific physical features as shown on the map. The object is to navigate to each of these controls and return to the start as quickly as possible. As the fastest wins, for the top competitors, this means travelling as fast as the local conditions allow. This normally means running, apart from where there are exceptionally difficult conditions.

Therefore we will consider the circumstances faced by a good orienteer over a short distance in a competition and then analyse some of these actions and reactions in detail. The following is a description of just a few paces of the progression of a good orienteer around a course.

The Orienteer is running in forest and the ground is from immediate prior experience, firm and even and the pace and footfall adjusted accordingly to allow for a hard landing, or impact, of the feet and for good purchase for propulsion. The visual focus is on overall long-range navigation and is aimed well ahead on the features in the way and on significant features to either side.

The Orienteer at this moment has, as expected, found a good firm base with his right foot, confirmed by the tactile sense of the sole of the foot on meeting the ground. Some of the muscles of the leg are accordingly contracting, propelling the body upwards and forwards. The left leg having completed its propulsion action is in the air moving forward. The position of the next placement of the left foot has been mentally programmed previously and as it descends at speed to the ground a firm sensory reaction at a specific point in the descent of the foot is expected.

The ground however is not firm at this point and in fact is very soft. As the foot descends into this soft ground to just 15 or 20 mm below the surface at least two warning ‘messages’ are sent to the brain. One through the ‘positional’ sense in effect says, “The foot has gone past the point where the ground should be.” The second, from the tactile sense of the sole of the foot through the shoe says, “The ground is not firm.” By this time the right foot has already left the ground and is in the air moving forward for the planned next pace.

Of the numerous mental and physical actions and reactions that occur at this instant the main ones are as follows.
The muscles of the left foot and leg are instructed to relax, to cancel the planned positional contractions for propulsion and to allow the foot to feel for a sound base under the soft surface.
The right leg is simultaneously instructed to shorten its pace from the planned long one and to stamp down as quickly as possible. This is in order to provide a more immediate support for the body and to be able to relieve the potential stress on left leg and foot if the solid base under the soft surface is found to be awkward or unsound.

At the same time the head and the eyes snap down from their focus further ahead to focus on the surface immediately in front. Firstly, if possible, to view the new placement position of the right foot and then to reprogram the subsequent placement of both feet.

It transpires that the soft ground under the left foot conceals a hard rigid object. As the foot descends a further 25mm into the soft ground it contacts the rigid object, perhaps a root or a stone, with the outer left front part of the sole. The right foot meanwhile has not yet descended to the ground to provide alternative support for the body. The left foot is, as stated, feeling for a base and the muscles are relaxed. The foot, ankle and leg cannot however sustain the stress involved in such an offset support position. So again the almost instantaneous reaction is for the left ankle and foot muscles to flex and allow the foot to cant to one side. The angle through which the ankle can rotate laterally is fairly limited and this limit is reached quickly in the continuing descent of the left foot. Once this angle is reached and stress on the ankle becomes severe, as indicated by pain signals to the brain, this initiates a reaction of moving the knee to the right to allow the lower leg itself to cant to that side.
Further if this action is insufficient to relieve the stress both on the ankle and the leg, it will need to be followed by the transfer of weight by, and an inclination of, the torso to the right. This transfer is better described as 'throwing' the weight of the body to one side as it is an extremely fast instinctive movement involving the muscles of the thighs and the spine and lower torso.

By this time the instructions to the right leg will have been to stamp down more urgently, but at the same time to be prepared for an unsure footing as this placement position has not been programmed. However if this is not possible to do this in time to relieve the left limb, and/or the stimulus is severe enough, the result may well be to continue with 'throwing' the torso to the right and consequently allowing a 'planned' fall in this direction. This fall would be a case of accepting the lesser of the two evils, in terms of potential injury.

All these co-ordinated actions and reactions are designed to prevent the left foot and leg, in these circumstances, from being subjected to stress of a magnitude sufficient to cause injury. Of course any planned fall would also be co-ordinated, involving the visual senses, as far as possible to avoid injury. Injuries may still be the result if the circumstances are unfavourable and/or the fall cannot be adequately controlled, but they may well be less serious than a broken ankle or leg.

It is clear that all of these sensory, programming and muscular actions and reactions take place simultaneously and at an incredible speed and that these are just a small part of the innumerable mental–physical signalling processes taking place concurrently.

All these various signals are being sensed, transmitted to the brain, received by it, processed by it, decisions made transmitted to the muscles, received by them and acted on, within minute fractions of a second. And this is not all, these processes are carried out on top of and concurrently with, innumerable other decisions as to foot placement two or three or more paces ahead, route choice, etc. etc. etc. This indicates that the eyes have to be able to register numerous factors simultaneously and means that the focus clearly cannot be on all these at one time. The brain is therefore controlling movement on the basis of images from all parts of the total cone of visual perception and doing so with astounding speed and organisation. This is a highly developed capability, requiring fast transmission of a huge amount information from the sensory areas to the

brain, processing it and referring to stored experience, and signalling back to the appropriate muscles. The muscles in use when running in these circumstances include the majority of the 600 main body muscles.
This is an extremely complex task in combining well-developed and fast mental programming and acute senses with excellent balance and fast, precise muscular reactions.

The speed of human physical reaction to stimulus in these circumstances can be roughly calculated by relating the velocity of the runner over the ground to the distance of the foot movement referred to earlier. A reaction instigated by 30mm of movement by the foot at a modest velocity over the ground of 4 metres a second would give a physical reaction time measured from stimulus to muscular contraction of about 0.007 seconds.

It is facile to compare the enormous power of the human brain to a computer. However to attempt to put this in some sort of perspective, no computer, if given just a fraction of the co-ordinational problem described above would, I suggest, be capable of solving it and issuing instructions within the necessary time constraints.

I suggest that the overall mental capacity necessary for such advanced bipedal co-ordination is not generally acknowledged and is well underestimated. This may well be due to the fact that in modern man this highly developed mental capability is generally not utilised.

Hominid Bipedal Motion

It is generally assumed that we evolved either from a quadrupedal or knuckle walking, forest floor dwelling ape such as the gorilla or from a tree dwelling ape such as the gibbon. The differences in the shape, dimension and the alignment of the skeletal bones between ape and man are significant. The progression therefore to a permanently upright posture would be governed by, amongst other things, the need for a substantial alteration in skeletal structure. It is clear that the process of natural selection leading to these changes would take a considerable length of time.

Before examining this progression however it is important to differentiate between an occasional bipedal capability and a permanently and fully erect bipedal locomotion.

Here we can look at our cousin the chimpanzee for clarification. The chimp is capable of standing almost upright and walking this way and it is clear that their sense of balance in this position is good. This locomotion however is ungainly for anatomical reasons and is not normally used and then only for short distances.
When in quadrupedal motion the facial plane is vertical and the placement of the rear feet is often positioned to either side of the front knuckle position.
It is quite evident that the reason for choosing this posture, apart from the anatomical, is for good visual coverage of the ground surface for both front and rear foot placements.
Accordingly therefore, while the chimp is capable of balanced upright motion, it normally chooses a quadrupedal locomotion.

As the example of the Chimpanzee shows, any hominid in the initial stages of the progression to fully upright would be capable of moving in a near erect posture. This

however would not normally be used except perhaps at a slow walk in a well known environment, when the tactile sense of the soles of the feet, more than the visual sense, would be used to test the ground surface for obstacles and secure placement.
However when the necessity occurred for a perambulation of any distance, in unfamiliar terrain or at any velocity, for good vision it would be imperative to angle the facial plane at or about vertical.

When in quadrupedal motion the attitude of the upper spine of a Chimpanzee is approximately horizontal to the ground. The attitude of the head on the spine is such that the facial plane is about vertical to the ground, or at an angle of 90 to the spine. The attitude of the facial plane of modern man is also about vertical to the ground as is now the upper spine. Thus, in the evolution of quadrupedal ape to fully bipedal man today, the spine has moved through an arc of about 90 while the facial plane has remained vertical.

Therefore if we evolved from a similar creature then this progression would involve a gradual change in the attitude of the top section of the spine, in relation to the ground surface, through an arc of about 90 to vertical. It would also involve a gradual change in the angle that the facial plane subtends with the spine from about 90 to parallel with it.

Progression from a Gibbon/MacauType Species

This theory has been promoted in recent times however in the complete absence of any hard evidence there are severe difficulties in explaining such a direct progression from arboreal to a savannah existence.
In any case the theory we are concerned with suggests A.Afarensis as our ancestor and accordingly the problem would still remain as to why it evolved from such origins over a long period and ended up with a visually inefficient and typically chimp-like skull structure.
Therefore and in the knowledge of the close similarity of chimpanzee and human DNA it is reasonable to assume for this argument that we evolved from a similar animal.

Evolutionary Progression from Quadrupedal to a Permanently Upright Posture

The progressive development of the locomotive capabilities of our ancestral line would logically have to be from knuckle walking, to walking with fingertips touching the ground, then to a crouched locomotion with the hands just above the ground and ready to support when necessary. From this point in the progression the front limbs contact the ground less and less frequently and the attitude in motion is one of a strongly crouched bent-kneed gait. At this point it can be said that hominid bipedalism began.

In all the early bipedal stages, a severely crouched attitude would be necessary both for good visual coverage of the ground surface and to maintain the centre of gravity of the whole body positioned over the feet. The change from quadrupedal to bipedal could be described as shifting the centre of gravity of the body progressively backwards from between the four supporting limbs to between the two rear limbs. Chimpanzees bear only 30-40% of the body weight on the front knuckles and the progression to bipedalism would therefore involve a gradual reduction of the weight supported by the front limbs to a point where all the weight was on the rear limbs. The centre of gravity would accordingly move to over the rear feet. The progression then would be a matter of maintaining the centre of gravity over the feet while the gradual straightening of the legs and the body, the re-alignment of the head on the spine, the change in the attitude of the facial plane relative to the spine etc. allowed a more and more erect posture in motion.

This crouched attitude would place an undue stress on the body muscles, in particular of the back and the legs. Consequently the amount of time actually spent in such a position would be kept to a minimum. While such stress would naturally lead to the progressive strengthening of the relevant muscles, this stance would nevertheless consume a lot of energy and accordingly there would be no incentive to maintain it unnecessarily. This resultant high-energy consumption would have a direct effect on stamina and would accordingly severely limit the ability to maintain a bipedal motion for any length of time, at any velocity. Accordingly there would have needed to be a very strong incentive to undertake a journey of any length and leave the security of the home base.

As the anatomical changes permit a more and more erect locomotion the level of muscular stress and the resultant energy consumption would reduce proportionately. The ability to remain in a bipedal stance for longer and longer periods and thus to roam further afield would correspondingly increase. It follows that the increase in efficiency would have an influence on the amount of time regularly spent in a bipedal stance. This would of itself tend to speed up the rate of progression.

The Bipedal Motion of Homo Sapiens Sapiens

When motionless man today stands with the centre of gravity of the whole body positioned over and between the arches of both feet. The head is erect on the upper spine and the spine arched slightly in order to position the weight of the head and the upper torso over the hips. This of course is the most efficient or energy conserving, high alert resting position. The focus of the eyes is about horizontal and the legs bent slightly at the knee.

When running however the spinal arch is straightened and the spine is angled forward from the hips. This moves the centre of gravity of the torso forward to balance the propulsion thrust of the legs. This thrust of the legs is angled upwards and forwards and the angle of thrust, as well as the angle of the torso at the hip, is dependent on the acceleration or velocity at that moment.

Inclining the upper spine forward has a secondary effect in that the comfortable position of the head on the spine also changes the inclination of the facial plane. This brings the comfortable focus of the eyes down from the horizontal to a point on the surface of the ground about 20-30 metres ahead and additionally extends the lower arc of visual perception back to cover the ground vertically under the body. This position of the focus of the eyes on the ground surface at 20-30 metres ahead is ideal for the observation of small obstacles and foot placement programming.
When running the knees are normally bent. The angle subtended between the upper and lower leg at the knee does not normally exceed about 160 in running motion, except when reducing speed.

Modern man therefore in forward motion adopts a crouched, bent-kneed stance, albeit a much more erect or advanced version than that practised by early bipedal hominids.

Co-ordination of A.Afarensis

Of course there is no real evidence as to the mental and physical capabilities of A.Afarensis. A comparison with modern man can therefore only be based on the capabilities generally and hypothetically attributed to the species together with the models and pictorial reproductions of it.

These reproductions show it fully and permanently upright with what is essentially a modern human torso, limbs and extremities, but with a smaller stature and with body hair or fur and with a head that is similar to that of a chimpanzee. It is suggested that it foraged for food on the open Savannah adding to its diet by hunting small game and scavenging. This implies that its upright mobility was good, having an appropriate level of endurance and speed over the ground.

Accordingly, when in motion here, it would need to concentrate visually, as do other species, on the terrain as a whole, planning it’s route as well as looking for potential food sources, and maintaining a watchful lookout for predators, etc. Simultaneously it would need to keep a sharp eye on the surface conditions ahead, noting difficulties and obstacles and where necessary adjusting pace, or direction to avoid them. Such vigilance would have been essential to survival in the circumstances, as one wrong step resulting in an injury could undoubtedly have had serious and even fatal consequences. Any inadequacy in this respect, of course would not only be potentially fatal for the individual, but in the long term would be fatal for the species in an evolutionary sense.

Here it has to be noted that its feet, while no doubt toughened with calluses, were by comparison with many other species living in the same environment, unprotected.

We can only conclude from all this that the level of bipedal co-ordination needed by A.Afarensis to be able to run safely in the Savannah at a speed sufficient to be able to hunt and to attempt to evade predators, would not and could not be far different to that of man today.

So if we accept the fully erect theory together with the capabilities generally attributed to A.Afarensis, we have a fully upright hominid with a torso and limbs similar to that of man today and with the head of an ape. Its attributes include good stamina and mobility, enabling it to roam at will on the open Savannah, all implying that it had good bipedal co-ordination. This suggests that A.Afarensis was 3.5 million years ago living in a manner not far removed to that of some ‘primitive’ tribes today.

This leads to the question as to how A.Afarensis evolved to this state and how this was achieved with a brain volume slightly larger that that of a Chimpanzee.

A Permanently Erect A.Afarensis?

The theory that A.Afarensis was our ancestor, was permanently and completely upright at 3.5 million years ago and was fully erect in motion as depicted has various implications, firstly for its apparent evolution to this state.

How long the implied evolution of A.Afarensis took from a quadrupedal to an upright locomotion would, in the current absence of any fossil evidence, be pure speculation. It is however clear that the necessary changes in the alignment, the shape and the dimension of most of the skeletal bones would take a very long time. Some indication of the period of time necessary to effect such evolutionary changes to the torso would be indicated by the time taken for the changes in the structure of the head as shown by successive dated fossil skull specimens of hominids from A.Afarensis to date. While some of these skull specimens may not be of our direct line, they generally show a significant and progressive change in structure over the period in question.

If this remarkable change in the dimension, shape and alignment of the skull components including the jaw took 3.5 million years, then one could reasonably assume that the equally significant changes in the skeletal structure below the neck would take a comparable period of time.

Accepting this theory therefore means accepting that the anatomical configuration of the body of A.Afarensis' predecessors below the neck altered significantly in a previous long evolutionary period while in the same period the structure and the cranial capacity of the head remained ape-like. Also in the subsequent period of 3.5 million years to date, while the head altered profoundly, the implication is that there was no significant improvement or change in either the structure of the torso or in the level of bipedal co-ordination.

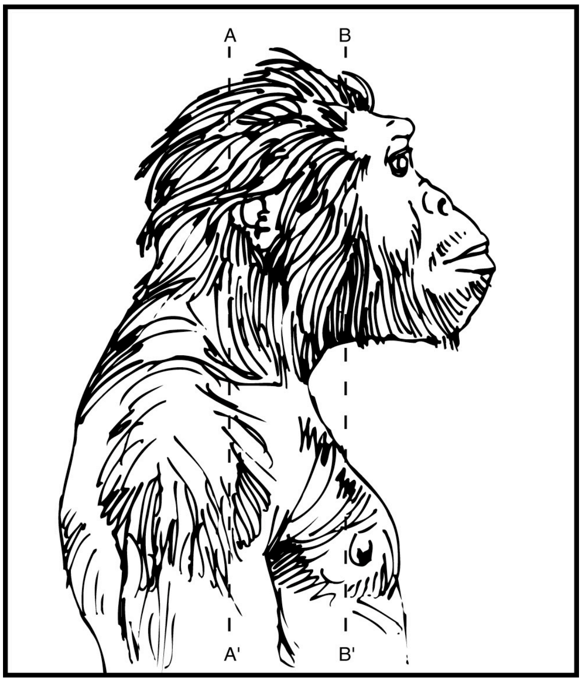
These changes to the skeletal structure below the neck over the last 3.5 million years would, according to the theory, have been mainly one of dimension and not alignment, some components having increased in length and cross section, while others to some extent have decreased. The most apparent result of these changes would be an increase in stature of about 15-20%.

By comparison in the same period the actual, recorded changes to the structure, shape and dimensions of the head are dramatic. There has been an expansion of the cranium and projection of it forward over the eye sockets. The capacity of the cranium has increased by more than 200%, represented by an increase from the 400ml of A.Afarensis to 1350ml today, and there has been a marked reduction in the size and projection of the jaw.

In referring to the models and representations of A.Afarensis and considering the question of muscular stress another factor is highlighted relating to the posture of the head and neck on the body.

Referring to the diagram below the approximate position of the centre of gravity of the body can be said to lie on the line A-A' and that of the head, as a separate entity, lies on the line B-B'.

It is clear that in an erect posture maintaining the attitude of the head as depicted would put a continual stress on the muscles of the neck and the upper back. This would therefore be an energy consuming and therefore inefficient attitude.



This highlights a problem that would have faced Johanson and his associate White when designing a model of an erect A.Afarensis. If the neck and skull were placed at an anatomically balanced and more appropriate attitude on the torso then the facial plane would be at an even more acute angle to the horizontal (see diagram below). This clearly does not suit the assumption that it was fully erect and led to the necessity of depicting that the vertebrae in the neck were arched forward allowing a more suitable positioning of the head and in particular of the attitude of the eyes.

Therefore if we accept that A.Afarensis was permanently and fully erect in locomotion, it would also follow that the long evolutionary process of becoming upright resulted in it having a restricted visual coverage of the ground and an inefficient attitude and posture of the head on the spine.

Such inefficient developments would clearly contradict the principles of Natural Selection.

However it is quite clear that for A.Afarensis to have a good safe, visual coverage of the ground surface it would have to have the facial plane of its ape-like head vertical. This would suggest therefore that it was not permanently erect in locomotion for any extended perambulation. The very ape-like structure of the head would indicate that it was still in the initial stages of the evolution to upright and that it would accordingly adopt a strongly crouched bipedal attitude when in motion on the ground.

All this leads to the re-examination of the hard evidence.

Fossil Evidence

Looking at the overall picture the facts are that the numbers of fossil remains identifiable as hominid from the period prior to 4 million years ago are non-existent, and from this date up to 100,000 years ago, they are very rare. Most are incomplete fragments and no complete skeleton has been discovered to date.

The famous ‘Lucy’ remains consist of about 50 components most of which are fragments, representing about 37 bones, or numerically less than 20%, of the over 200 separate bones of a complete primate skeleton.

In contrast we have a much better idea of the skeletal structure of dinosaurs of 65,000,000 years ago than we do of our suggested ancestral line prior to 100,000 years ago.

This rarity of hominid examples is undoubtedly due mainly to the dispersal and destruction of remains by predators and scavengers before burial was practised in the last few tens of thousands of years.

The fossil evidence on which the theory of a fully erect A.Afarensis is effectively based is, to say the least, minimal. Some experts dispute that these fossils provide conclusive evidence that hominids at this time, and indeed that some subsequent species, were fully erect.

Therefore it can be stated that neither the ‘Lucy’ fossils on their own, nor any other A.Afarensis fossils, provide indisputable and unequivocal proof that this creature was fully erect in locomotion in the manner of man today.

The Laetoli Evidence

The Laetoli footprints combined with the separate and, save by assumption, unconnected ‘Lucy’ and other A.Afarensis fossils are generally considered as confirming that hominids were fully erect over three million years ago.

These footprints are indeed significant and the main arguments put forward in favour of these prints as indicating permanent upright stance are that they show evidence of an arch in the foot thus enabling the foot to exert leverage in walking, similar to the action of modern man. Also that the big toe is aligned closely with the others, rather than widely separated or prehensile as in gorillas and chimpanzees.

The prints were made in a deposit of volcanic ash, moistened by rain and preserved by the subsequent drying and hardening of the ash. They show a large creature walking by the side of a smaller and it is thought that another small member was following literally in the larger’s footsteps.

There may be many explanations for how these prints came to be made and the following is one interpretation based on an attempt to look at this situation from the practical point of view of the creatures at this time.

In the aftermath of a local volcanic eruption they are travelling, perhaps to escape the after effects of this eruption. They face a situation of a soft, possibly wet, new laid layer of ash and are forced to cross this to a safer position. This is an unknown and possibly dangerous crossing, as the ash could be deep in places, it may be slippery and perhaps it is still hot, it could also obscure sharp stones or other potentially injurious objects. All these things make this a traumatic and stressful situation and the traverse would not be attempted if there were an alternative route or option.

In these circumstances they abandon their normal independent mode of travel and move close to the large member for support and assistance. To be able to support the smaller one, or ones, the larger must hold on to them naturally by their front limbs. They feel their way with their feet, treading very carefully. The larger holds one hand out to the side and perhaps the other out to the rear for the one stepping in his tracks, which is of course a safer option than walking to one side and making its own. The fact that the rear smaller creature lengthens its stride to step in the larger’s footsteps is a further indication of stress.

With respect to the closed toe aspect of the prints, those who have walked barefoot in deep, soft, wet mud will be aware that the natural and unavoidably instinctive reaction to these conditions is to try and keep your toes tightly held together.
Also when walking on hot sandy beach the instinctive reaction is to place as little flesh as possible in contact with the hot material. The toes are tightly curled up close together and the foot canted to one side to try and keep the more sensitive inner part of the sole off of the sand.

Observation of Gorillas and Chimpanzees show that the normal positioning of the toes of the feet in both quadrupedal and bipedal locomotion is with the front toes extended and the prehensile toe extended to the side. However both are capable of clenching the toes of the foot into a ‘fist’ with the front toes from the first joint bent back under the sole of the foot and the prehensile big toe brought into alignment with them.

It is therefore a possibility that a primate of a similar species capable of bipedal motion could have made these prints in this manner.

This is of course speculation, however it is clear that while these prints may be evidence of bipedalism they, like the 'Lucy' fossils, cannot be considered as conclusive proof of a bipedal locomotion as upright as that practised by man today.

Conclusions

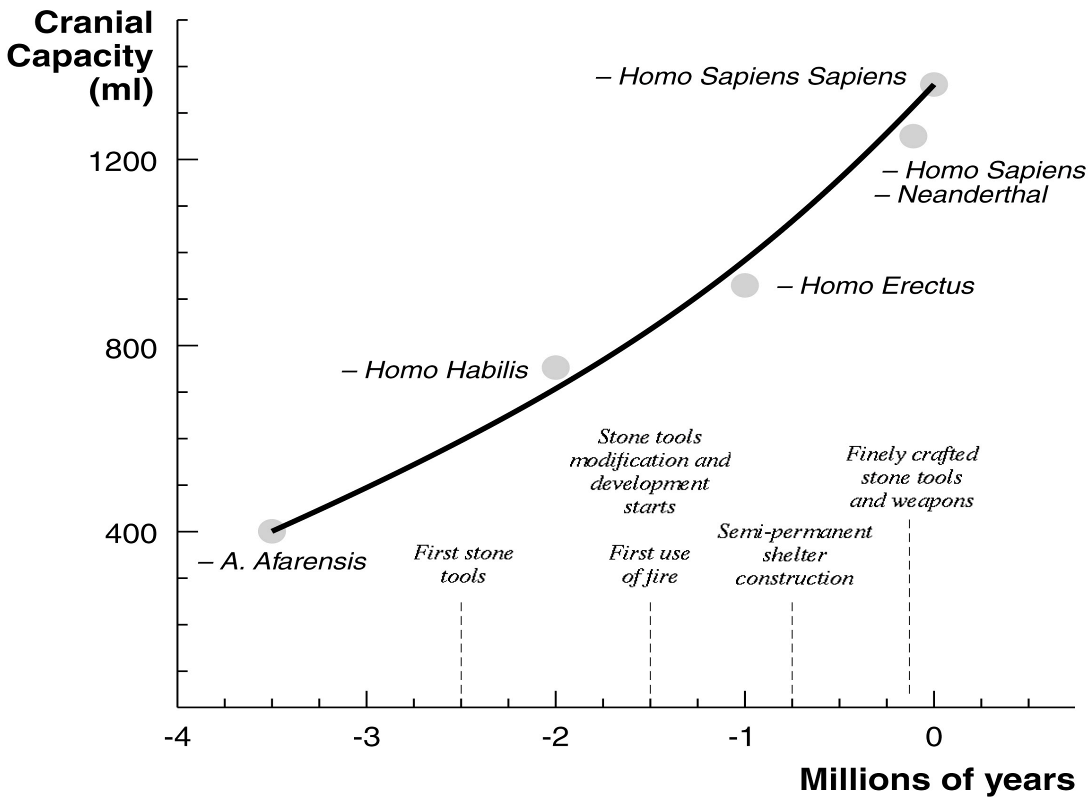
The fundamental questions about the evolution of man still remain unanswered. These are why did an arboreal ape become erect and how did this progression proceed.
If these questions are applied to the assumption that A.Afarensis had achieved this remarkable transition 3.5 million years ago then these questions, in the absence of any fossil or other evidence, remain not only unanswered but in all probability unanswerable.
However if these are asked on the basis that A.Afarensis was still in the transitional stage of becoming fully erect then a logical pattern appears.

Essentially the only remains that are indisputable indications of the mental development of pre-historic man are the rare skull components, the numerous stone and later bone tools, evidence of the use of fire at about 1.5 million years ago and later the construction of semi-permanent shelters from about 800,000 years ago.

The fossil records of hominid skulls from 3.5 million years ago show a progressive but slow increase in the capacity of the brain cavity. While all these examples are not necessarily of our direct line, if A.Afarensis was an ancestor the capacity of the cranium has increased by about 250% during this period.
If we measure the average rate of increase in volume from A.Afarensis to H.Habilis and further to H.Erectus we get a figure of 1ml increase every 4750 years and from H.Erectus, at about 1million years ago, to date we get a rate of 1ml every 2500 years.
This expansion of the cranium was combined with and concurrent with its change in shape and movement forward expanding the forehead upwards and forward over the eye sockets. At the same time in profile the projection of the jaw has receded considerably leaving the nasal extension effectively in place.

Stone tool making began about 2.5 million years ago preceded, it can only be assumed, by wooden implements and perhaps the use of naturally occurring materials such as sharp stone flakes or the shells of molluscs or crustaceans. However for over one million years from this point there is little evidence of any significant development or modification of the earliest dated examples and essentially the same type of stone tool was produced. At about 1.5 million years ago modifications and improvements then began to appear at an increasing rate. Different materials were used and there was a progressive development in the variety of tools and weapons produced, leading ultimately to the finely crafted axes, arrowheads, etc. of the latter part of the Stone Age.

The diagram below shows the curve of the progressive increase of cranial capacity of successive hominid specimens over the period in question. If a curve could be drawn of the progressive development of the types, the quality and the finish of tools and weapons over the same period then while this may not have precisely the same characteristics it would clearly show an approximately concurrent and exponential change.



As discussed earlier the progression from a chimp-like quadrupedal locomotion towards the fully erect would in the initial stages be very slow. As the posture became more and more erect and energy efficient, the result would be an ability to spend more time in a bipedal posture. The reduced expenditure of energy in locomotion would lead to increased endurance and consequently result in the possibility of a greater range of movement.
The rate of evolutionary progression to upright locomotion would accordingly tend to increase exponentially.

This suggests that a graph showing the progression from a quadrupedal to an upright locomotion would show similar exponential characteristics to that of the expansion of the cranium and that of the development of tool manufacture.

The inference is clear in that, in the absence of any conclusive evidence to the contrary, it is therefore logical to suggest that the progression to upright kept pace with the changes in the shape and dimensions of the skull. The movement forward of the brain cavity and the recession of the jaw, or in other words the realignment of the facial plane about the eye sockets, is accordingly an indication of the progressive change of the attitude of the upper spine to a near erect position in locomotion. This would suggest that this progression has been ongoing and only recently been ‘completed’ in the last one hundred thousand years.

This lends credence to the theory that the use and the carriage of food, tools and weapons was an incentive to use a bipedal locomotion and was therefore an influential factor in the evolutionary process.

However it would also answer the serious difficulties that arise from presenting A.Afarensis as being a fully erect, hunter/gatherer roaming the savannah at will in a family group within a larger social group or tribe in a manner not far removed from that of some so called 'primitive' tribes that still exist today.

The problem is that all this suggests intelligence, as well as good co-ordination, and begs the question of how this mental capability was achieved with a cranial capacity only slightly larger than that of a chimpanzee.
This then gives rise to the difficulty of explaining the subsequent threefold increase in cranial capacity in the period to date. This huge increase can hardly be explained either by the evident increase in manual dexterity or the beginnings of oral and later written language, or the concept of 'self', reason, abstract thought, etc.

The human brain is an inordinately expensive organ to maintain, representing just 3% of body weight and consuming over 20% of the energy resources of the body. As stated earlier, nature in the process of natural selection, does not waste resources in producing, and maintaining, a component that is not utilised.

It is clear therefore that the increase in cranial capacity simply kept pace with the increasing efficiency of the progressively more upright posture in motion. This improved efficiency leading to an increase in stamina or endurance, which in turn widened the range of potential movement from a home base. Better bipedal co-ordination would result in improved agility and speed over the ground and all these factors together with the need to process, store and access and react to an increasing amount of information more and more rapidly would result in an obvious need for an expanded mental capability. This progression would neatly coincide with the development of manual dexterity, oral communication, etc. and the combination of all these factors would clearly explain the observed exponential expansion of the brain.

This idea is also reinforced by, and can explain the enigma of the co-existence of the relatively primitive Neanderthal Man with Cro-Magnon Man during the last one hundred thousand years. The prominent jaw and other cranial features such as the prominent ridge of the forehead together with the round shouldered stance suggest that Neanderthal was still in the latter stages of evolving to an erect posture. Cro-Magnon man was at a more advanced stage and was more erect and its lighter structure indicates that it would be faster and more agile. This in turn would suggest that it was better co-ordinated and perhaps more dextrous in the use of weapons. In competition for the same food sources Cro-Magnon would have a distinct advantage. It would be like pitting a racehorse against a carthorse.

The possibility is that both evolved from the same original species and were somehow separated geographically. Environmental and other factors may have resulted in differing adaptations at different rates and when the two subspecies again came into contact through migration Cro-Magnon had evidently won the race to the more efficient erect posture and subsequently eliminated Neanderthal.

A.Afarensis cannot have been as erect in locomotion in the same manner as that of man today. Its mobility on the ground was limited, its bipedal co-ordination poor. Its diet was overwhelmingly vegetation. It inhabited the forest and did not venture willingly in to open country. Its level of intelligence was possibly more advanced than that of modern chimpanzees but not by much. A.Afarensis was still an ape.