

Temporal spatial data, the gait cycle and gait graphs

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Temporal spatial parameters

Distance parameters

Human walking is achieved by moving the feet forward alternately. A **step** is the movement of one foot in front of the other. A **stride** is made up of a step for one foot followed by another step for the other. In healthy walking each step or stride is very similar to the next and the overall pattern of movement repeats. The pattern of movement that repeats is called the **gait cycle**. Given that this pattern just repeats continuously any point in time could be thought of as the start of the cycle. The convention adopted almost universally however is to think of the gait cycle starting when one foot makes contact with the floor, **foot contact**, and continuing until the next occasion when that foot makes contact with the floor. (In healthy walking it is the heel that contacts the ground first and this instant is often referred to as **heel-strike**. If we want a terminology, however, that can be used for all gait patterns, healthy or otherwise, then foot contact is the preferred term).

Step length is the distance that one part of the foot travels in front of the same part of the other foot during each step. **Stride length** is the distance that one part of a foot travels between the same instant in two consecutive gait cycles. It doesn't actually matter which instant is chosen but it is very common to find that this is measured at foot contact. Given that during a stride the left foot moves in front of the right by right step length and the right then moves in front of the left by left step length then it can be seen that stride length must be the sum of left and right step lengths. On average the stride length for one side must be the same as that for the other (otherwise the person will not be walking in a straight line) regardless of how asymmetric other aspects of the gait pattern may be. In asymmetric gait patterns however the step lengths for the two sides may be different.

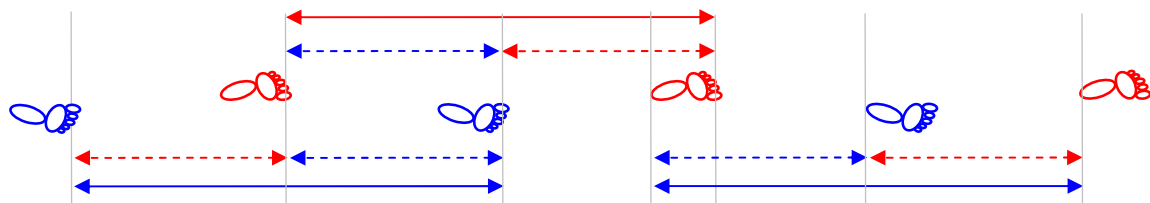


Figure 1 Step (dashed) and stride (continuous) lengths for symmetrical walking. Note that both step and stride lengths are equal for both sides, stride length always equals the sum of left and right step lengths, step and stride length are independent of the part of the foot being used as a reference for measurement (toe on first two strides and heel in last)

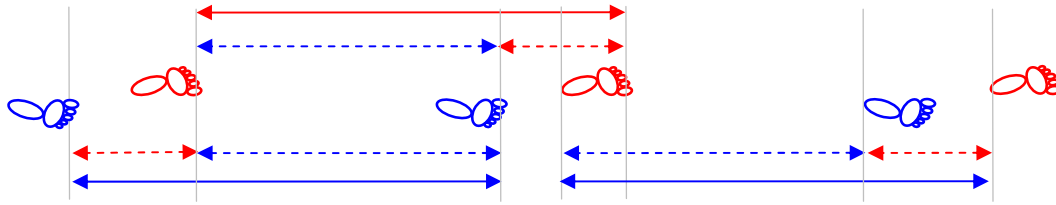


Figure 2 Step (dashed) and stride (continuous) lengths for asymmetrical walking. Note that left and right step lengths are different but all the other relationships commented upon in Figure 1 are preserved.

Step width is a measure of the medio-lateral separation of the feet. Specific definitions of the term vary quite considerably in the literature. What is certain is that *step width* is really a function of the stride (it is the same for left and right steps) and that **stride width** should be the preferred term. It can be seen from Figure 3 that step width will depend on the point on the foot used as the basis of measurement. The distance between the heels is a commonly used measure which can easily be measured from video or foot prints. In 3-dimensional gait analysis the distance between the medio-lateral ankle joint centres is probably the most useful definition.

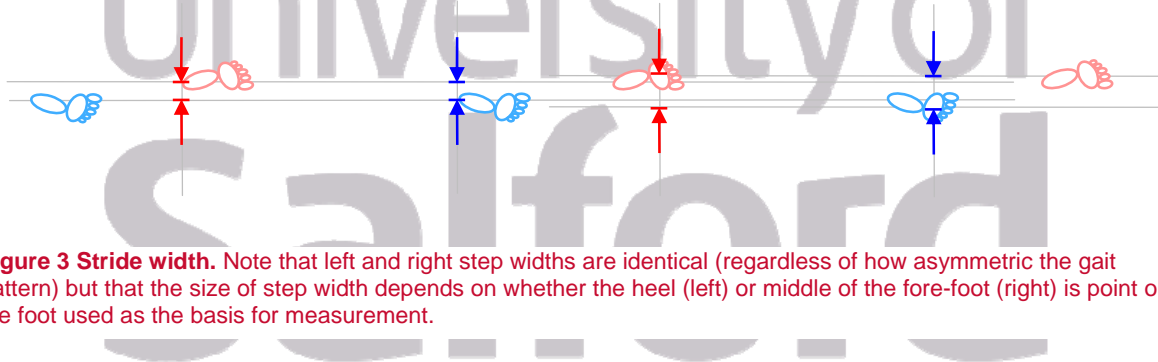


Figure 3 Stride width. Note that left and right step widths are identical (regardless of how asymmetric the gait pattern) but that the size of step width depends on whether the heel (left) or middle of the fore-foot (right) is point on the foot used as the basis for measurement.

Cadence, stride length and walking speed

Stride time is the duration of one gait cycle. As with Stride length it does not matter which point of the gait cycle it is calculated from but by convention it is taken as the time between successive foot contacts on the same side. Rather than talking about stride time, however, it is more normal to refer to the duration of the gait cycle in terms of the **cadence**. To keep things simple it would be useful if cadence always referred to the number of strides per minute but often (perhaps more often) it is actually used to refer to the number of steps per minute (twice the number of strides)¹.

If cadence is the number of strides per minute and we know the stride length then the walking speed can be calculated as the product of cadence and stride length:

$$\text{walking speed} = \text{cadence} \times \text{stride length}.$$

¹ **Step time** is sometimes defined separately analogously to step length particularly when symmetry of gait is being considered. It needs to be used with care. In particular it is important to note that cadence, which is related to the stride, has to be calculated on the basis of stride time (regardless of whether it is expressed as strides per minute or steps per minute).

Phases

Single and double support

To describe the processes that occur during walking then it is useful to divide the gait cycle into a number of phases. The simplest such division is to divide the cycle for a given limb into the stance phase, when the foot is in contact with the floor, and the swing phase, when it is not. In healthy walking at comfortable speed this happens about 60% into the gait cycle (some studies suggest 62% is a closer estimate). The point at which stance ends is **foot-off** (often referred to as toe-off).



Figure 4. A single stride divided temporally into stance and swing phase.

To develop this scheme to further sub-divide the gait cycle it is possible to depict what is happening to the other leg at the same time (see Figure 4). If the walking pattern is symmetrical then the **opposite foot contact** will occur half-way through the gait cycle. Opposite foot off (from the preceding gait cycle) precedes this by the duration of the opposite swing phase (approx 40% of the cycle in normal walking). This subdivides stance into first double support (from foot contact to opposite foot off), single support (from opposite foot off to opposite foot contact) and second double support (from opposite foot contact to foot off).

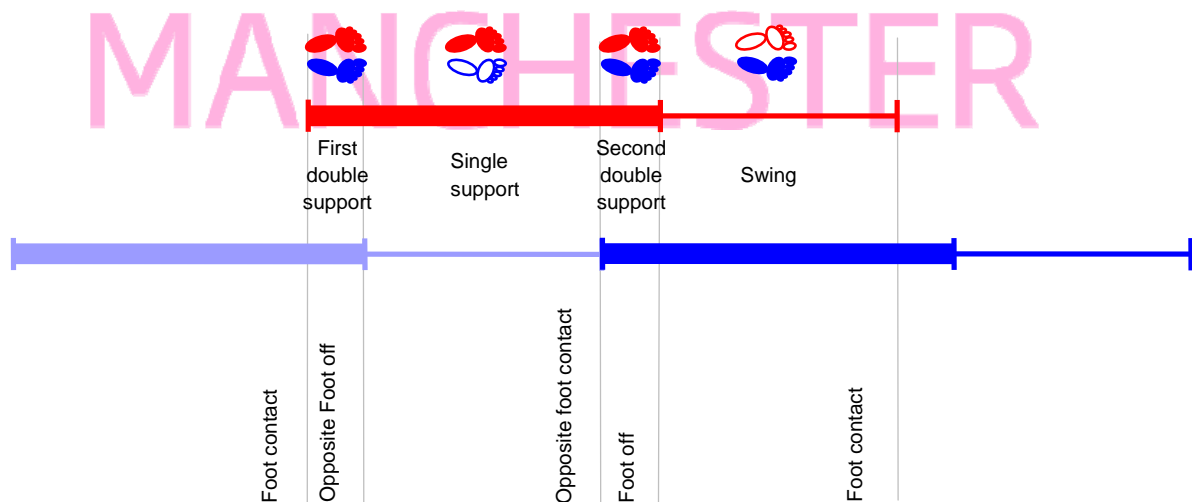


Figure 5 Subdivision of gait cycle into periods of double and single support on the basis of events occurring on the opposite limb

According to Perry

The scheme above still leaves quite long periods in single support and swing without subdivision and Jacqueline Perry suggested the definition of additional phases. She saw **initial contact** as a separate phase occurring over the first 2% of the gait cycle and named the rest of first double support **loading response**. Single support was divided equally into **mid-stance** and **terminal stance** and second double support called **pre-swing**. The swing phase was then divided equally into **initial**, **mid-** and **late swing**.

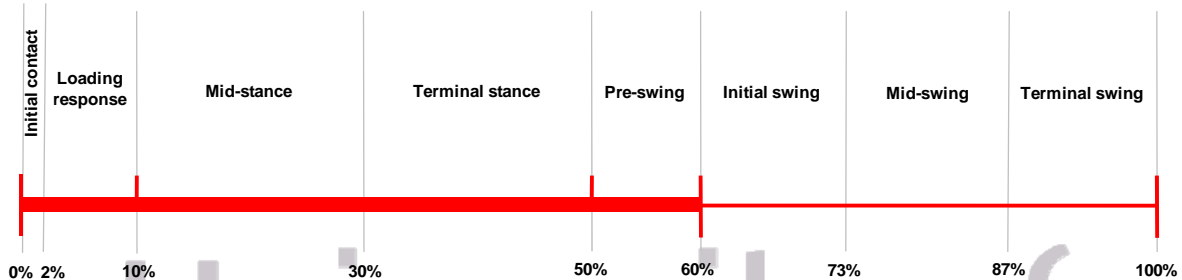


Figure 6 Sub-division of the gait cycle as suggested by Perry

Adapted from Perry

Although almost all text books on clinical gait analysis recommend Perry's sub-division of the gait cycle there are some problems associated with it. Initial contact is clearly an instant and not a phase and we already have a term for it (foot contact). It is clear from the most cursory inspection of the vertical component of the ground reaction that loading occurs throughout first single support so *response* is not a particularly well chosen term. Mid-stance doesn't occur in the middle of stance and terminal stance doesn't occur at the end of it. The precise way she chose to determine the transitions between the sub-phases of single support and swing are in terms of characteristics of healthy walking and often do not translate well to other walking patterns. It is clear when listening to many gait analysts speak that they actually use mid-stance to refer to the middle of stance and terminal stance synonymously with pre-swing.

Some people do not like pre-swing being a phase of stance but this does reinforce the cyclic nature of walking and that one of the most important functions in late stance is to prepare for swing. It may well be, using the same reasoning, that pre-stance is a good alternative term for terminal swing.

A further issue is that in order to correlate what is happening on one side to what is happening on the other at the same phase in gait it would have been useful if single support and swing (being the same phases of gait but observed with regard to different limbs) had been sub-divided into the same number of sub-phases. In healthy walking there are actually very few changes in function throughout single support and simply using mid-stance to refer to this entire phase is probably all that is needed most of the time. Where more sub-division of this phase is necessary it is suggested that it be divided into three to match the three sub-phases of swing. It is suggested that subdivisions of single support and swing are into roughly equal thirds based on timing.

Figure 7 presents an adaptation of Perry's terminology that will be used throughout this course. Where several terms are listed they are seen as synonymous, usage will depend on context.

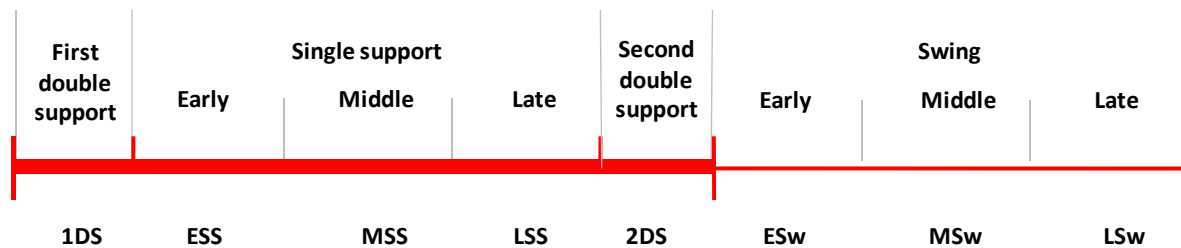


Figure 7 Terminology adapted from Perry and used throughout this course.

Gait graphs

Dividing the gait cycle

Whichever gait variable we want to look it is calculated as a pattern of data that varies constantly with time. Because gait is approximately cyclic however we can divide this pattern up into a number of discrete gait cycles and we do this assuming that any gait cycle begins at foot contact and continues until the next occurrence of foot contact for the same foot. The data represented on a gait graph thus represents data from just one gait cycle. We can also mark in the timing of toe off as a vertical line across the whole graph and opposite foot off and opposite foot contact as short vertical lines at the top of the graph.

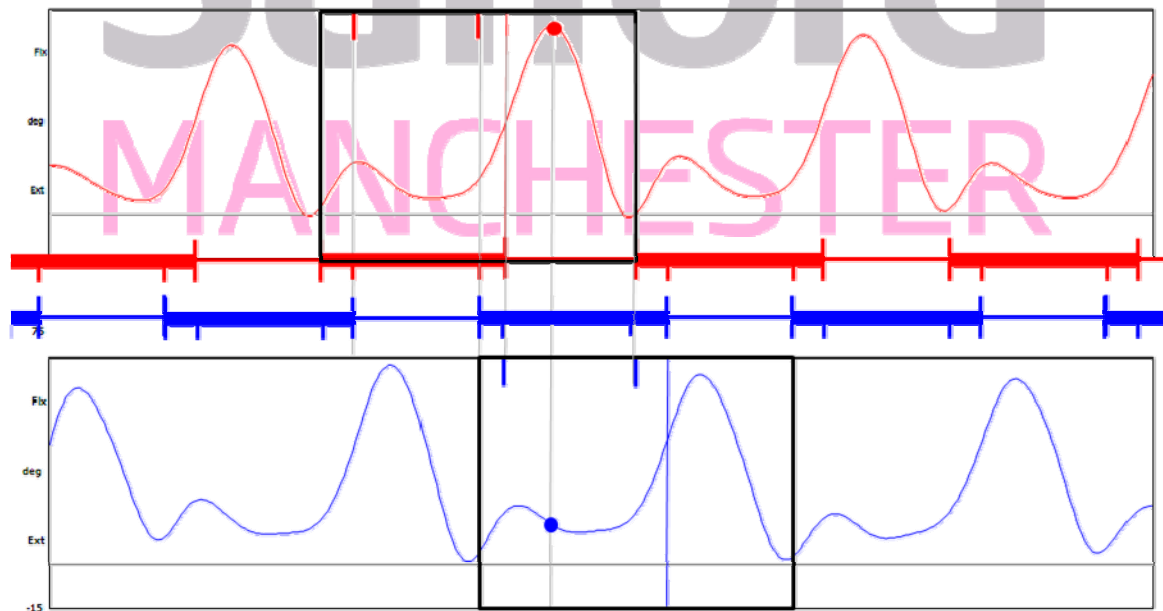


Figure 8 Extracting a gait graph for a gait cycle from data for the whole gait pattern for knee flexion on the basis of foot contact data.

In **Figure 8** data from left and right sides is plotted in real time and it can readily be seen that that the gait graph for the right gait cycle is taken from a different time than that of the left gait cycle and that the timing events marked on the graph relate. If we want to know what is happening on the left and right legs at

the same instant in time we have to look at different points on the gait graph. To a good approximation with most patient's data the left side and right side data is separated by half a gait cycle and this is generally a good enough rule of thumb if you want to compare data between the different sides.

Gait is not exactly cyclic so there is some variability from one gait cycle to the next. It can be very useful to know this when interpreting gait data clinically so it is becoming more and more common for gait data from several strides to be superimposed on the same graphs (see Figure 9). In Figure 9 these are actually different gait cycles from the same walk. It is more common to find a number of gait cycles from different walks.

Comparative data for healthy walking

Clinical interpretation of data is enhanced by plotting comparative data obtained from healthy people in the background, often as a grey shaded area (see Figure 9). This can also be extremely helpful in allowing the analyst to recognise which graph is being looked at and be more quickly orientated to the data.

There is some debate about whether a range of ± 1 or 2 standard deviations about the mean should be plotted. Given that there this is only plotted as a guide to interpretation and not as a basis for formal statistical tests then there is little point in getting too tied down in the technicalities of this issue. Having data differ from the mean by at least 2 standard deviations, however, would normally be taken as a minimum for it being described as differing from the reference range. In this course the widespread practise of displaying the mean ± 1 standard deviation is adopted.

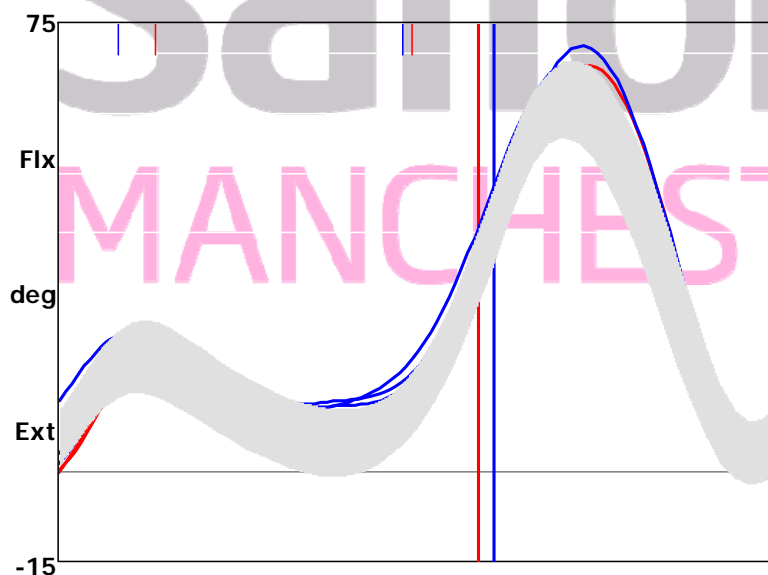


Figure 9 Gait graphs with data from multiple cycles and comparative normal data.

Individual graph layout

Clinical interpretation of gait analysis data is much easier if the data is always presented in the same format. Patterns in the data can be more easily recognised and the analyst can be sure that apparent difference on graph arisen genuinely form difference in the data and not from the way it has been plotted.

Particular issues are the aspect ratio graphs and the scales used for axes. The aspect ratio is the ratio of the height to the length of the rectangle in which the data plotted. In this course all data will be plotted on graphs with an aspect ratio of 3:4. Scaling depends on the units in which different parameters are measured and also the range of change in the data. Whenever a particular variable is plotted anywhere in this course, however, it will be plotted with the same scaling of axes.

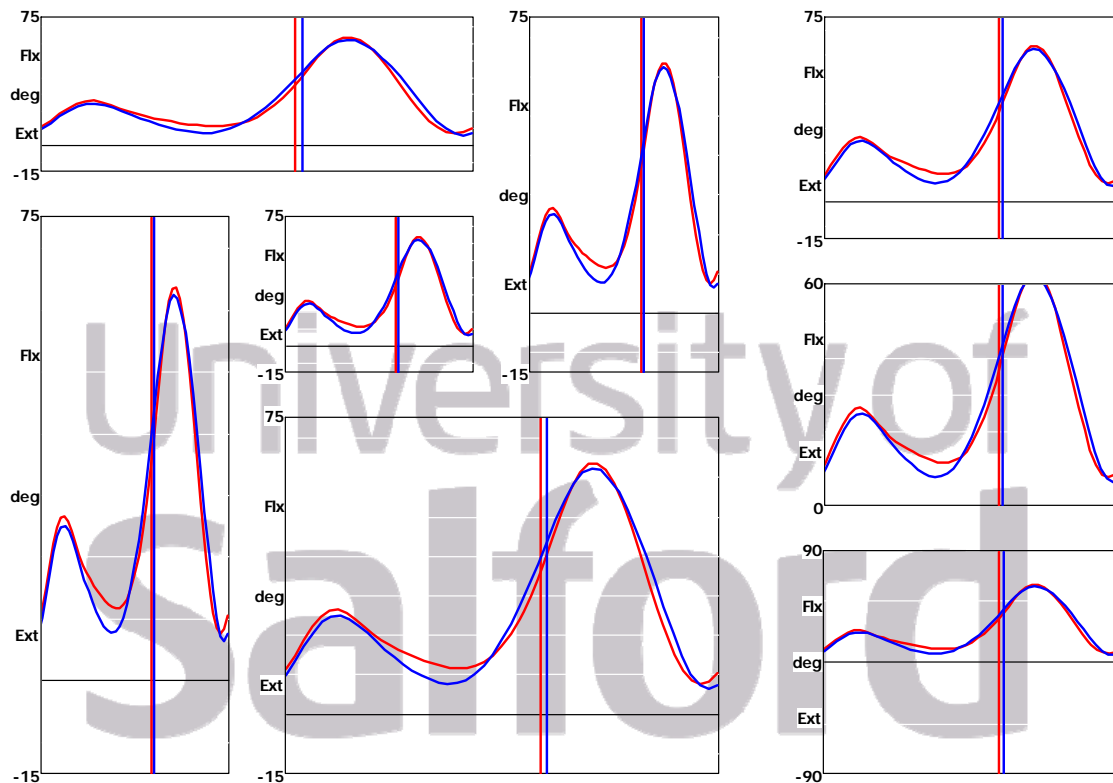


Figure 10 Illustration of how different aspect ratios (left) and different scaling of variables (right) affects how data looks.

Graph arrays

As well as standardising the way individual graphs are presented it can also help in clinical interpretation if the layout of graphs on a page is always the same. As with the scaling of different variables, not all types of data can be grouped in the same way but all arrays of similar graphs used in this course will generally be identical. Where 3-d data is presented the left-most column will have data from the sagittal plane, the central column, data from the coronal plane and the right-most column data from the transverse plane. Generally data from the more proximal segments, joints or muscles will be presented towards the top of the page and distal data towards the bottom.

Although standardising output makes data more easily interpreted within a single centre it is important to recognise that there are few standards imposed across different gait analysis services and there should be sufficient labelling of axes and graphs to interpret the data without relying on a knowledge of the standard layout. It can also be important to know the source of any data displaying this with the graphed data can be extremely useful.

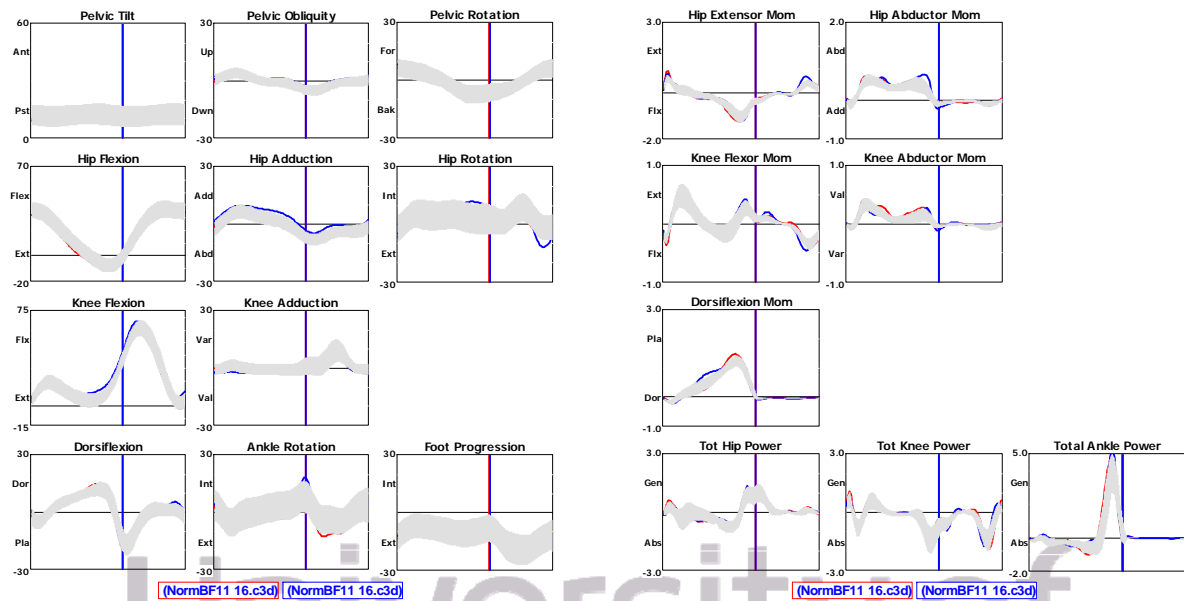


Figure 11 Standard arrays of kinematic (left) and kinetic (right) data as they will be plotted throughout this course