An Investigation of Postural Control with Respect to a Point of Interest

Richard McAleer

Title and subtitle

An Investigation of Postural Control with Respect to a Point of Interest. (Undersökning av postural reglering med avseende på en vald punkt).

Abstract

The ability to maintain postural stability is important in many everyday activities. It is also necessary in many cases to stabilise something other than simply the body.

Investigated in this study is the relationship between the stability of a subject on a force platform and that of a glass of water that they were given to hold. Tests were performed on nine healthy subjects who were exposed to erroneous proprioceptive information via vibrators strapped on their calf muscles. A force platform was used to measure their sway and the SELSPOT co-ordinate monitoring system was used to monitor the position on the glass.

Although no obvious consistent differences in the postural stabilisation with and without the glass were noticed, it was observed that in most subjects the change in motion of the glass in response to the stimulus was less than that of the body, both with their eyes open and closed, which would indicate a strategy in operation to maintain constant the position of the glass, which is distinct from that to stabilise the body. This is consistent with a hypothesis of the human being able to stabilise an object, or limb, outside the frame of the body without changing the basic postural control function.

Final Year Project Report
Richard McAleer

An investigation of postural control with respect to a point of interest.

Supervisors: Rolf Johansson, M.D., Ph.D.
                         Måns Magnusson, M.D., Ph.D.
                         Per-Anders Fransson, M.Eng.
                         Prof. D.J. Murray-Smith

Contents

Appendix

A: SELSPOT Position Monitoring System

B: Software

C: MATLAB

D: Data

E: Suggestions for further work.

Abstract

The ability to maintain postural stability is important in many everyday activities. It is also necessary in many cases to stabilise something other than simply the body.

Investigated in this study is the relationship between the stability of a subject on a force platform and that of a glass of water that they were given to hold. Tests were performed on nine healthy subjects who were exposed to erroneous proprioceptive information via vibrators strapped on their calf muscles. A force platform was used to measure their sway and the SELSPOT co-ordinate monitoring system was used to monitor the position on the glass.

Although no obvious consistent differences in the postural stabilisation with and without the glass were noticed, it was observed that in most subjects the change in motion of the glass in response to the stimulus was less than that of the body, both with their eyes open and closed, which would indicate a strategy in operation to maintain constant the position of the glass, which is distinct from that to stabilise the body. This is consistent with a hypothesis of the human being able to stabilise an object, or limb, outside the frame of the body without changing the basic postural control function.

Introduction

Maintaining good postural control is necessary in many normal situations, both in walking and static stance. In many of these situations it is required to keep stable a foreign object, from walking with a cup of coffee, to shooting a handgun in competition. Most people would be a lot more anxious about holding, for example, a delicate crystal glass than a piece of wood, and it seems natural to assume that this anxiety would have an effect on the stance of the subject. It has been found that trained pistol shooters in competition exhibit sways very similar to those of untrained subjects, due to that fact that their training is focused on the stability of the hand and not the body, whereas rifle shooters, who due to the nature of their weapon require a more stable posture, exhibited sways far less than those of normal subjects [3]. The point of interest in this study was chosen to be a glass of water. It is of interest to investigate what effect this foreign object has on the ability of the subject to maintain posture, to see whether their strategy for maintaining postural control changes and to try and compare the relative stabilites of the foreign object and that of the test subjects.

Materials and methods

The test subjects consisted of nine healthy adults aged between 21 and 26 years (mean 23.2). Six of them were male. All were given instructions to refrain from alcohol for twenty four hours prior to the tests.

Each subject underwent four tests:

        A:With the glass and eyes open.
        B:With the glass and eyes closed
        C:With eyes open
        D:With eyes closed.

The order in which these test were taken was different for each subject. Each subject was offered a break in between tests until they felt comfortable to proceed.

During the tests involving the glass the subjects were asked to hold the glass with their forearm straight out infront, perpendicular to the torso and their elbow bent at ninety degrees but, without being held against the body. In the other tests they were asked to let their arms hang at their sides. When they had their eyes open the subjects were asked to stand with their head straight forward and to focus on a picture on the wall, thus keeping the visual information received by each subject consistent. The subjects were asked to prevent the water in the glass from spilling.

Headphones were used to play music to the subjects during the tests so as to remove the auditory information from the environment, and again, to make the tests consistent between subjects.

The stimulation was provided via two vibrators strapped to the calf muscles to induce sagittal sway by exposing the test subject to erroneous proprioceptive information[4]. The vibrators used were heavier than those used in clinical tests with a 1mm amplitude, a power of 850 mW and a vibration frequency of 60 Hz. The vibrators were turned on and off in a Pseudo Random Binary Sequence (PRBS)[2,(see chapter 8)]. Before the onset of stimulus a 15 sec rest period was used to monitor normal sway and glass position. The duration of the stimulus was 105 sec giving a total test time of 2 min.

The subject was standing on a force platform that measured shear forces and torques in the sagittal, lateral and vertical directions.

The glass used was a 400 ml beaker filled to such an extent that it was required to be held very carefully to prevent the water from spilling. Attached to the glass were three infra-red LEDs from the SELSPOT system (from the Selective Electronic Co AB Sweden) that were monitored via two cameras to register a three dimensional record of the position of the glass during the test (see appendix A for a description of the method).

A PC computer (Hewlett Packard 486 DX2 66 MHz) was used to generate and output the stimulus voltage and to read the input voltages from the force platform, SELSPOT system and stimulus. The sampling rate used was 25 Hz.

The software to do this was written using the Labview Graphical Programming for Instrument package (see appendix B for a description of the software).

The force platform was placed 1.2 m away from the camera lenses. The centres of the camera lenses were 81cm apart and the cameras converged with an angle of 40 deg approximately 118 cm away from each camera lens. This provided a useful space of approximately 40 cm cubed for the glass to be visible to both cameras, this size of space was required due to the differences in heights of the test subjects.

Analysis of the data was done using MATLAB for windows (see appendix C for a description and transcript of the most important m-files used).

Analysis consisted of :

A: Comparison of the sagittal and lateral torque variances for the different test conditions.

B: Estimation of a third order ARMAX model for each test condition and translation of this into Swiftness Stiffness and Damping parameters[1].

C: Comparison of the power spectral densities of the glass motion for open and closed eyes.

D: Comparison of the change in variance of glass position before and after the onset of stimulus with that of sway position.

E: Comparison of the change in variance of glass velocity before and after the onset of stimulus with that of sway velocity.

Results
A: Comparison of the torque variances for the different test conditions.

The following diagram shows the torque variances in the sagittal direction for every subject in all the tests. The sagittal torque variance gives an indication of the amount of sagittal sway induced in response to the stimulus. The rest period was removed prior to the calculation of these variances.
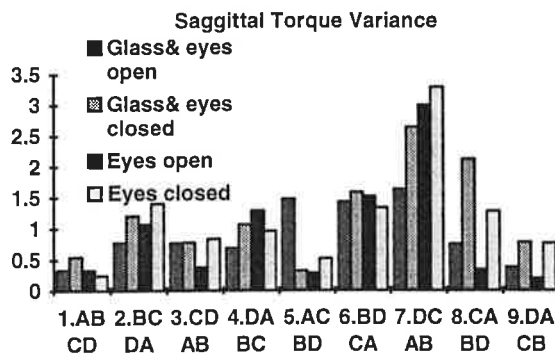
The letters indicate the order in which the tests were taken, where A is with the glass and eyes open, B is with the glass and eyes closed and C is with the eyes open.

Test subjects 1, 8 and 9 exhibit an increased sway with the glass in both the eyes open and closed conditions.

Test subjects 2 and 7 exhibit a decreased sway with the glass in both the eyes open and closed conditions.

Test subjects 3, 4, 5 and 6 do not exhibit any consistent differences between the test conditions.

Test subject 5 exhibits a sway much greater on their first test than any other test and test subject 7 exhibits values that decrease with the order of the tests.

Lateral Torque Variance
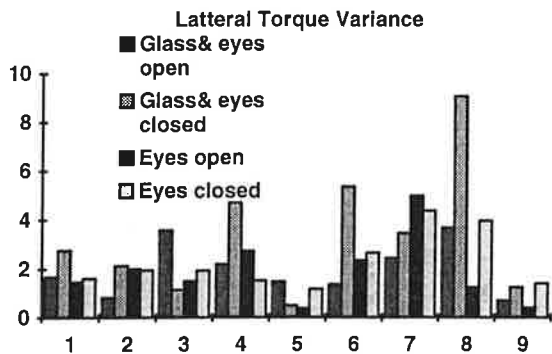
The patterns here are similar to those of the sagittal torque for all subjects except subject 2 who exhibits an increase in lateral torque variance in the closed eyes test from without the glass to with the glass. This, however, is not very important since the vibrators are mounted on the calf muscles with the intent of inducing a sagittal motion.

B: Estimation of a third order ARMAX model for each test condition and translation of this into Swiftness Stiffness and Damping parameters.

The sagittal torque data was fitted to a third order ARMAX model from which stiffness swiftness and damping parameters were determined, consistent with the method presented by Johansson et al[1]. Where swiftness indicates the quickness of the subject to respond to the stimulus, stiffness indicates the ability of the test subject to resist the stimulus and damping gives an indication of the ability of the subject to recover from the stimulus.

The stiffness, swiftness and damping parameters for all four test conditions are shown below.

Glass & Eyes open

Glass & Eyes closed


Eyes open

Eyes closed

5
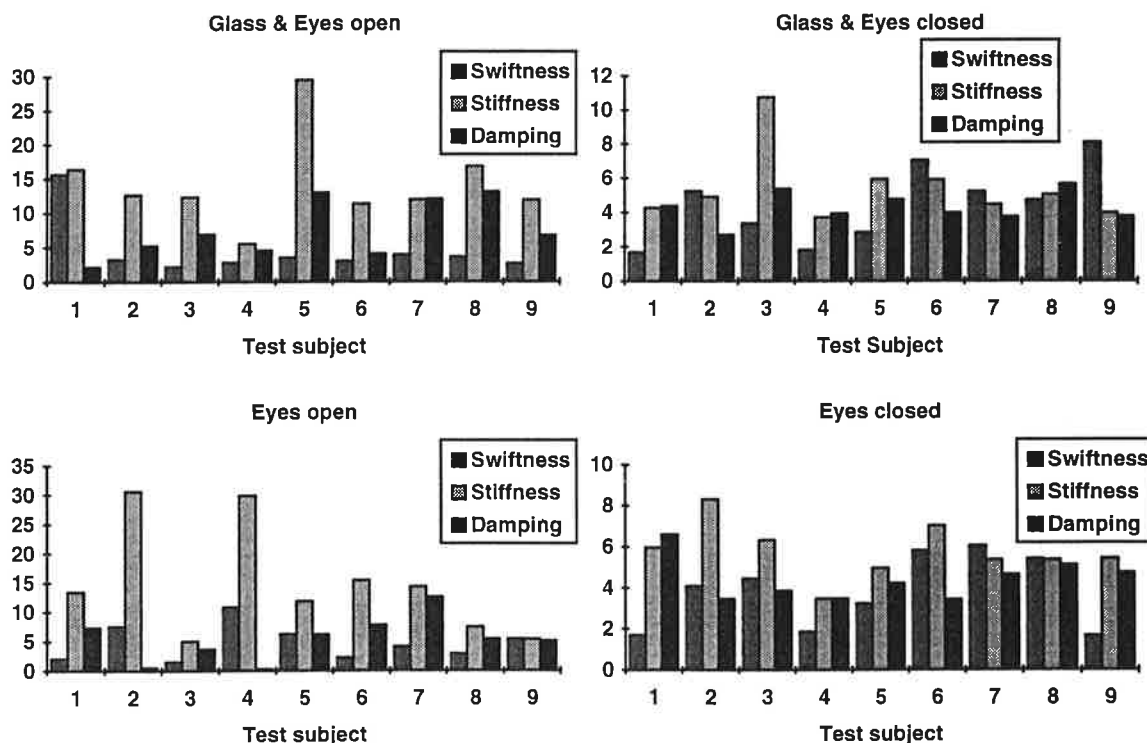
Five subjects exhibit a decrease in swiftness in the eyes open condition when given the glass. Three of these subjects along with two others also exhibit a decrease in swiftness with their eyes closed. The other four subjects all exhibit an increase in swiftness when given the glass in both the eyes open and eyes closed tests.

Five subjects exhibit an increase in stiffness in the eyes open tests when given the glass. Two of these and one other subject also exhibit an increase in stiffness when their eyes are closed. The other four subjects all exhibit a decrease in their stiffness parameters when given the glass both with and without their eyes open.

Six test subjects show an increase in damping when given the glass in the eyes open tests. Four of these and one more test subject also exhibit an increase in damping in the tests with their eyes closed. Two subjects exhibit a decrease in damping when they receive the glass in both the eyes open and eyes closed test.

Test subjects 2 and 4 exhibit very strange parameters in the eyes open test. They have abnormally large stiffness parameters and abnormally low damping parameters. The data used to create these models has been looked at and appears to be free from any interference, e.g. crosstalk from the stimulus, that could account for this. It is, however, considered that they are not accurate results.

It is natural to look at the mean values for these results to try and remove any influence that the order of the tests could have on the data.
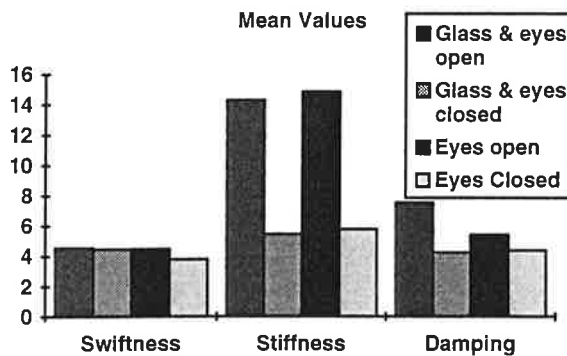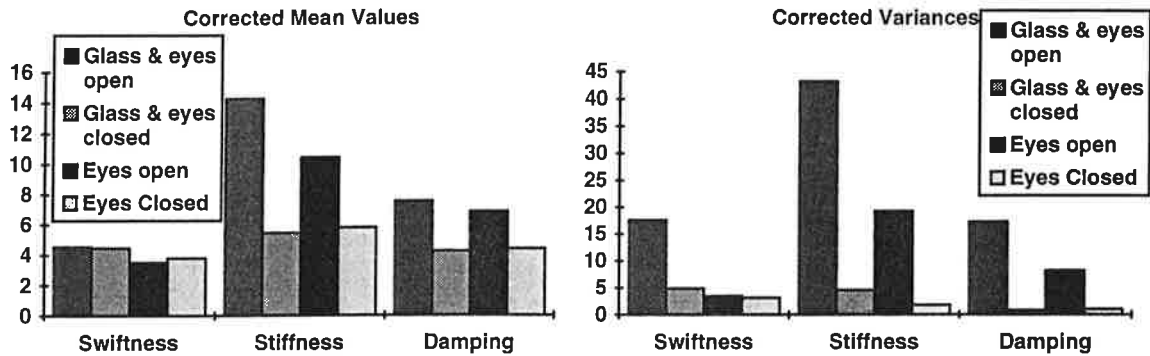

From this it appears that the only difference in these parameters with respect to the introduction of the glass is a slight increase in the value of the damping parameter. This would indicate an improved ability to recover from the stimulus.

It should be noted, however, that the variance values for all the parameters are very high in the tests where the subject has their eyes open.
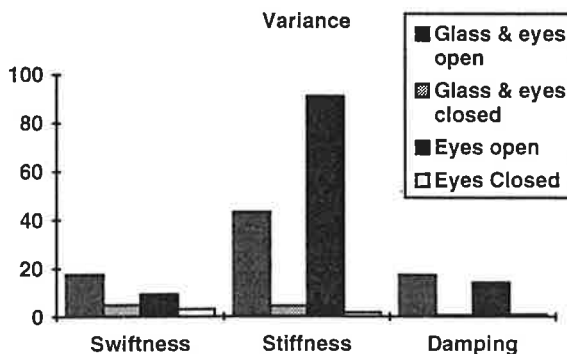
If it is the case that the results for subjects 2 and 4 in the eyes open test are invalid results then these should be removed and the mean values recalculated with the remaining data. The results of this and the variances for these results are shown below:
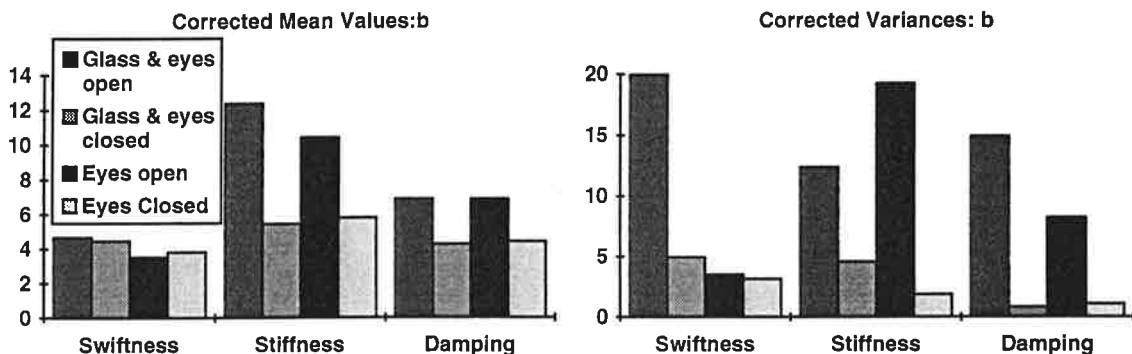
Corrected Mean Values

Legend: ■ Glass & eyes open, ▨ Glass & eyes closed, ■ Eyes open, ☐ Eyes Closed

Categories: Swiftness, Stiffness, Damping

Corrected Variances

Legend: ■ Glass & eyes open, ▨ Glass & eyes closed, ■ Eyes open, ☐ Eyes Closed

Categories: Swiftness, Stiffness, Damping

This shows slight increases in all parameters in the open eyes condition particularly in the stiffness.

These variances are still very high especially in the stiffness with the glass and eyes closed. This appears to be due to the results of test subject five who has a stiffness almost double that of any other remaining in any test condition and comparable with those stiffnessess of the two subjects removed from the eyes open condition.

If this subject is removed from this test and the mean and variance recalculated again, the following results are attained:

Corrected Mean Values:b

Legend: ■ Glass & eyes open, ▨ Glass & eyes closed, ■ Eyes open, ☐ Eyes Closed

Categories: Swiftness, Stiffness, Damping

Corrected Variances: b

Categories: Swiftness, Stiffness, Damping

Although these variances are greatly improved from the original values they are still too high to draw any definite conclusions about differences in postural control between the test conditions.

C: Comparison of the power spectral densities of the glass motion for open and closed eyes.

The power spectra of the motion of the glass with and without the eyes open were compared. All subjects except number 6 showed an increased motion of the glass at low frequencies with their eyes closed compared with their eyes open. The frequency at which the glass movements became similar for both conditions varied between 0.3 and 1 Hz, which is consistant with the bandwidth of visual contributions to postural control.

D: Comparison of the change in variance of glass position before and after the onset of stimulus with that of sway position.

7

It was of interest to compare the positional stability of the glass with that of the test subject, this was done as follows.

The sway path of the test subject was calculated giving a pair of X and Y coordinate vectors. These were used to calculate a resultant vector for each sample instant, this indicates the magnitude of the displacement of the force centre of the body from the origin of the X and Y coordinates.

Similarly for the glass coordinates a resultant of the X, Y and Z coordinates was calculated, this indicating the distance of the first LED from the point of convergence of the cameras.

The variance for both these resultants was calculated for both before and after the onset of the stimulus. The variance from after the onset of stimulus was then divided by that from the rest period to give an indication of how much the positional stability was affect by the stimulus.

The following table shows these ratios, of the variance from the stimulation period to that of the rest period.

Subject	Sway Open	Glass Open	Sway Closed	Glass Closed
1.	4.667	4.257	2.304	1.205
2.	7	3.5798	6.083	15.037
3.	10.5	1.7	5	1.728
4.	1.769	1.833	10.2	3.3913
5.	8	7.462	6.83	15.8
6.	6.397	33.9	2.1595	54.5
7.	9.933	5.399	11.154	4.576
8.	5	2.99	1.381	0.758
9.	22.156	1.523	6.909	1.568

The value obtained for the glass was then divided by that obtained for the sway path, thus giving an indication of the relative positional stability of the glass compared to that of the test subject.

The following ratios were obtained:

Subject	Eyes open	Eyes closed
1.	0.912	0.523
2.	0.5114	2.472
3.	0.162	0.3456
4.	1.0362	0.332
5.	0.9328	2.313
6.	5.2994	25.237
7.	0.5435	0.4103
8.	0.598	0.549
9.	0.0687	0.227

A value of one indicates that the glass position and that of the subject responded to the same extent to the stimulus a value of a half indicates that the glass responded half as much as the test subject.

These results can be depicted thus:

Relative Positional Stability
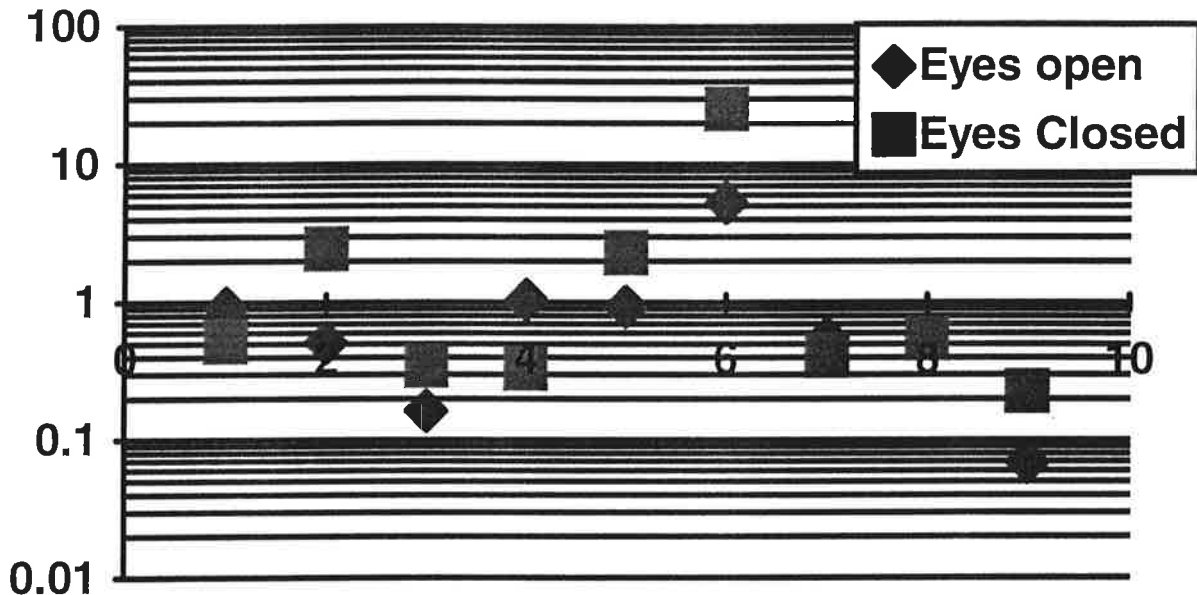
It can be seen that seven of the test subjects stabilised the glass position more successfully than that of their body with their eyes open. Two of those and one of the others have values within 0.1 of 1 indicating that the stabilities of both the glass position and that of the subject are very closely related.

With their eyes closed six subjects stabilised the glass more successfully than themselves. The subject with the most unstable glass was the same as in the eyes open test, subject 6.

E: Comparison of the change in variance of glass velocity before and after the onset of stimulus with that of sway velocity.

The variances of sway velocity and glass velocity were compared in the same way as position.

The following table shows the ratios of the variance from the stimulation period to that of the rest period for the velocities of both the glass and the test subject.

Subject	Sway Open	Glass Open	Sway Closed	Glass Closed
1	2.203	5.4286	1.6244	0.0689
2	1.366	2.777	1.5538	1.9375
3	1.0649	4.1786	1.7186	0.75
4	1.248	1.2105	2.79	3.622
5	2.074	7.455	1.583	9.5
6	0.987	22	1.41	32.3
7	2.556	3.556	2.507	2.777
8	1.1507	4.85	1.522	1.351
9	7.165	1.3	2.407	1.7117

Again, dividing the value obtained for the glass by that of the sway path the following ratios are obtained.

Subject	Eyes open	Eyes Closed
1.	2.464	0.043
2.	2.0329	1.2468
3.	3.9239	0.4364
4.	0.96995	1.2982
5.	3.5945	6.0013
6.	22.29	22.9
7.	1.391	1.1077
8.	4.215	0.888
9.	0.181	0.711

These results can be depicted as follows:

Ratio Glass/Sway Velocity Variance Change
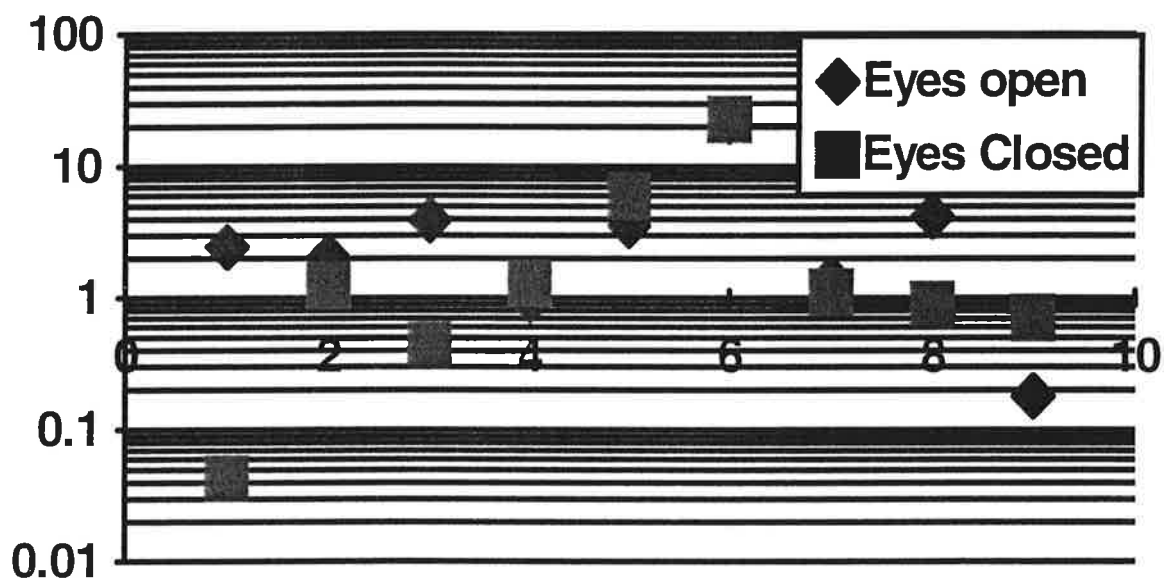
This shows that the glass velocity responded more to stimulus than sway velocity in all but two cases with the subjects eyes open and in five cases with the subjects eyes closed.

Discussion

The abnormally high stiffnessess and low damping parameters of test subjects 2 and 4 in the eyes open without the glass test would seem to indicate that they were ignoring the stimulus very well, implying an immunity to it, but also not recovering from the stimulus well, which would imply that it was having a large effect on them. These results appear to be contradictory. It may be possible that the stimulus was strong enough to induce a postural control strategy that involved the hips and knees instead of just the ankle which would invalidate the inverted pendulum model, that these parameters are used to describe, and requires the assumption that the body is rigid[1]. This however would require a very large deviation of the body bringing the body centre of gravity infront of the subjects feet which seems unlikely since the tests here involved the eyes open without the glass. It is more probable that there was something wrong with the stimulating vibrators, i.e. either or both were not functioning properly, which would explain the apparent immunity to stimulus suggested by the very high stiffness parameters, although none of the test subjects reported any discrepancy in the vibration sensation between the tests. This could also explain the very high stiffness of subject five in the eyes open with glass test although the damping parameter in this case is also very high. Another unusual result in the case with the glass and eyes open is the very high swiftness parameter of test subject one, almost seven times greater than their swiftness in any other test. Although this could be due to the presence of the glass, or the fact that that it was their first test, it seems unusual that any differences should be so great.

From the sagittal torque variance results it can be seen that subject 1 sways least with their eyes closed and without the glass which is unusual since visual feedback is regarded as a factor that improves postural stability, it should be noted that this was their final test. This when taken with the remarks mentioned previously about subject 7 exhibiting torque variances that decrease with the order of the tests and of the unusually high torque variance of subject 5 in their first test, would seem to indicate that the vibration stimulus used was probably too strong for at least some of the test subjects, and caused great differences between tests due to an increasing familiarity to the stimulation sensation. This could, in part, explain the lack of a consistent differences between the stiffness, swiftness and damping parameters of having the glass and not having the glass.

It was observed from some of the glass position plots that there appears to be high frequency movements around a low frequency path in the motion of the glass for some of the test subjects. This could indicate a searching on the part of the test subject for a more comfortable position in which to hold the glass, although this has not been investigated in this study.

From the results comparing the change in glass position variance with that of sway position it is seen that the position of the glass appears to be more stable than that of the body i.e. the subject stabilised the glass absorbing the perturbation. In the tests with their eyes open it can be seen that most of the test subjects stabilised the glass position more successfully than their body. The only subject in this case with a value much greater than 1, indicating a much greater postural stability than that of the glass was subject 6. Similar results were recorded for the case with the eyes closed, but here two more subjects appear to stabilise the glass not as well as the body.

If the sagittal torque variance results are compared with the results of the glass/sway relative positional stability measurements we find that subjects 1, 8 and 9 all sway more with the glass than without both with their eyes closed and open, but they all successfully held the glass more stable than their bodies. This could indicate that in these cases the stability of the glass is at the expense of that of the body.

Subjects 1, 4, 7 and 8 all swayed more with their eyes closed and with the glass than with their eyes open and with the glass but appear to have a better relative control over the glass position with their eyes closed. Which would seem to indicate that when their eyes were

closed they were concentrating more on the glass than themselves. Conversely subjects 2, 6 and 7 swayed more with their eyes closed and with the glass than with their eyes open and with the glass but the relative stability of the glass seems to have suffered. In the case of subjects 2 and 6 this could be explained because the test involving the glass with their eyes closed was the first one they took part in and as such was the most difficult for them, while when they came to do the test with the eyes open and the glass they were more familiar with the stimulus sensation and were therefore able to devote their concentration to stabilising the glass. Subject 7 seems to exhibit an adapting tendency through their sequence of tests with respect to the sagittal torque variance, it is very possible that this learning procedure is also responsible for the stability of the glass increasing in the second test that it is involved in. Subject 3 appears to have swayed to nearly the same extent both with their eyes open and closed with the glass (very slightly higher with the eyes closed), and exhibits a better relative control over the glass position with their eyes open. This also seems to indicate an adaptive tendency in the sway of the subject with respect to the stimulus, since the eyes closed with glass was the last of the tests that this subject undertook, and as therefore, might exhibit a lower sway than would be expected.

Subject 6 exhibits very poor relative control over the glass position. This could be due to the fact that subject 6 was taken from the hospital staff, and was the only test subject to have had experienced the vibration stimulus before, as part of a different study but without the glass, and therefore that it had a lesser effect on their sway path than on those of the naive subjects.

Looking at the model parameters of swiftness, stiffness and damping.. The differences in the model parameters are greater between the tests with the eyes open and closed than between those with and without the glass. This can be seen from the diagram shown earlier for the model parameters for all four test conditions, if subjects 2 and 4 are discounted from the eyes open test, and subject 5 from the eyes open with glass test, for the reasons previously stated. If any adaption to stimulus is ignored, the stiffness, swiftness and damping parameters calculated, seem to indicate that any changes in the strategy of a test subject to maintain posture with respect to the inclusion of the glass are on a personal level and in most cases are very slight. This would concur with Pyykkö with respect to the sway of trained pistol shooters being similar to that of untrained individuals i.e. that the test subjects stabilised the foreign objects without altering their own postural control strategy, although they were looking at sway velocity and not at estimated model parameters.

If the model parameters are looked at on the personal level it is found that, again discounting the tests previously mentioned, that four out of six subjects exhibited an increase in stiffness when given the glass with their eyes open but only three out of nine in the eyes closed situation. This would appear to indicate that the closing of the eyes has in most cases a greater effect on the postural control of a subject than the inclusion of a foreign object that requires to be stabilised. The fact that the stiffness increased in the eyes open case when the glass was included would indicate that those subjects became less sensitive to the stimulation because of the glass, but there are two subjects who both exhibit a decrease in their stiffness parameters when given the glass both with and without their eyes open, showing that they become more susceptible to the stimulation due to the glass.

Comparison of the damping parameters between tests shows a more consistent trend with only two subjects showing a decrease in damping due to the glass in both the eyes open and eyes closed cases. The fact that the other subjects all exhibited an increase in damping would indicate that they recovered from the effects of the stimulus better when they were in possession of the glass.

Examination of the mean values for the swiftness parameter would seem to indicate an increased speed of response to stimulus in the tests involving the glass. However, looking at

the results on an individual subject basis, it is found that the way that the swiftness parameter changes is far from consistent.

It is very probable that the order in which the tests were taken had an effect on the model parameters and any differences found cannot be connected purely to the inclusion of the glass in the problem. Conclusive identification of a change in strategy to maintain posture with respect to an external point of interest would require the tests undertaken to have a consistent effect on the posture of the test subject between tests. It is felt that the tests performed in this study rely too heavily on their order and the invalidness of some of the tests raises questions as to the accuracy and reliability of the others, these problems could be overcome by using a more subtle and reliable stimulus.

Conclusion

It was found that the majority of individuals tested stabilised the position of the glass they were holding more than their body position both in those tests with the eyes open and closed. It is hypothesised that this is done by continually compensation for changes in the velocity of the glass due to the sway of the subject.

Comparison of the estimated model parameters of swiftness, stiffness and damping failed to find any consistent differences between the tests with and without the glass, although this may be due to malfunctioning stimulus, and large adaptive differences between tests due to a stimulus that induced erroneous proprioceptive information to too great a degree.

Examination of sagittal torque variance also failed to provide any obvious consistent differences between the tests with the glass and those without. If these tests were to be undertaken again it would probably be wise to use less severe vibrators and to provide the test subjects with a learning session involving the vibrators so as to reduce the effect of the initial stimulus on the results. However, the present findings are consistant with the hypothesis that humans have the ability to stabilise an object outside the the frame of the body without altering their own postural control strategy.

References

1.R.Johansson, M.Magnusson, M.Åkesson. "Identification of human postural dynamics". IEEE Transactions Biomedical Engineering Vol BmE-35 1988, 858-869

2.R.Johansson "System Modelling and Identification" Prentice Hall 1993

3.I Pykkö, H Aalto, R Ilmarinen, Ekähkönen,"Postural Stability during race in medal winning shooters" , Disorders of posture and gait, pp 321-324, 1990

4.I Pykkö ,GÅHansson,LSchalén, NGHenrikssen,CWennmo,MMagnusson. "Vibration-Induced body sway". Computers in neurootological diagnosis, pp 139-155, 1983

Appendix A.

The SELSPOT position monitoring system.

The SELSPOT system used to monitor the the position of the glass consists of a pair of cameras and several LEDs that emitt infra-red light. The cameras each contain a photodetector that registers the position of each LED in its field of vision. The SELSPOT system returns a set of voltages that are linearly related to the X and Y coordinates of the LEDs seen by either camera, where X is the horizontal direction and Y is the vertical. The LEDs are turned off and on successively at a rate of 50Hz. The voltages recorded for each LED from either camera are stored on sample and hold gates at seperate outputs, from where they were read by the AD board of the computer, the voltages range from -5V to +5V. The LEDs are required to be seen by both cameras during the test otherwise a voltage of zero is returned when the LEDs move out of range. The cameras have an resolution accuracy of ten bits which gives 1024 possible values for the voltages in either direction. The useable space for the tests performed here was approximately a 40cm cube, giving a smallest recordable difference of 0.39mm.

The cameras were at a height of 137cm with a distance of 81cm between the centres of the lenses. The force platform was placed 120cm from the lenses with its front parallel to the imaginary line between them and with its left edge infront of camera 1.

The main problem with the cameras was that their field of view diverges away from the lens such that the same voltage can represent many different actual coordinates.

The calibration of the SELSPOT cameras was done as follows (the results obtained from this procedure can be found in appendix D).

The LEDs were attached to a spirit level placed 10cm apart from each other. LEDs 1 and 2 were used for camera 1 and LEDs 1 and 3 were used for camera 2. Values were obtained for the voltage that this distance of 10cm represented both at 1m distance from the cameras and at 1.5m from the cameras. These were then used to calculate scale factors at both distances in both the horizontal and vertical planes. These scale factors were then used to determine how much the ratio of volts to distance changes as the LEDs move away from and towards the cameras.

A simplified diagram of the arrangement of the equipment is shown below. The cameras were arranged such that they and their point of convergence formed an isoceles triangle in the horizontal plane. The distance between LEDs 1 and 2 was 28mm, that between LEDs 1 and 3 was 35mm.
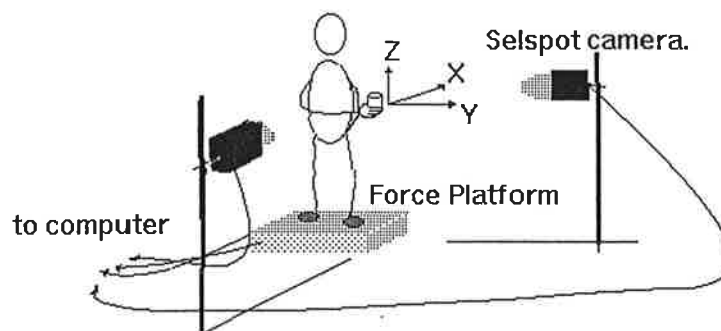
Calculation of glass orientation:

The SELSPOT markers on the glass are were positioned as below, thus enabling a three dimensional measurement of the position and the angle of the glass to be obtained .
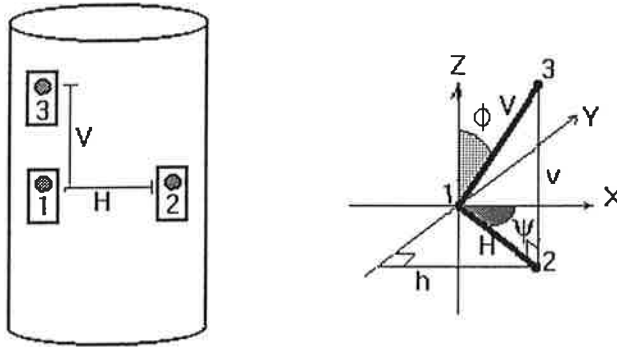

Camera 1 was used to identify markers one and two, and camera two to monitor markers one and three. This was necessary because of the lack of available inputs to the AD board on the computer. The angles ψ and φ can be calculated from the measured distances between the markers (h and v), and their actual lengths (H and V).

thus:

$$\psi = \cos^{-1} \frac{h}{H} \qquad \text{(Similarly for } \varphi.\text{)}$$

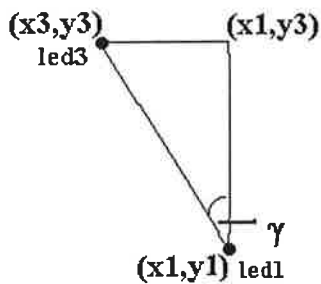The other angles can be calculated from the following diagrams:

From Camera 1:
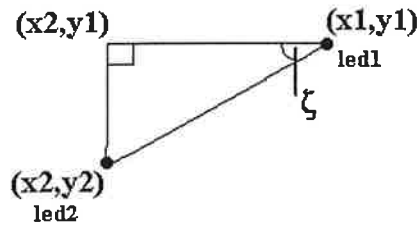
where

$$\varsigma = \cos^{-1} \frac{\left(x_1 - x_2\right)}{\sqrt{\left(\left(x_1 - x_2\right)^2 + \left(y_1 - y_2\right)^2\right)}}$$

From Camera 2:

where

$$\gamma = \cos^{-1} \frac{\left(y_3 - y_1\right)}{\sqrt{\left(\left(x_3 - x_1\right)^2 + \left(y_3 - y_1\right)^2\right)}}.$$

Calculation of the three dimensional position of the glass.

The calculation of the position of the glass in three dimensions is done as follows:
(A transcript of the matlab m-file for this procedure can be found in appendix C.)
(camera1 is on the left.)
The following diagram indicates some of the distances required to calibrate the cameras and calculate the positions of the LEDs.
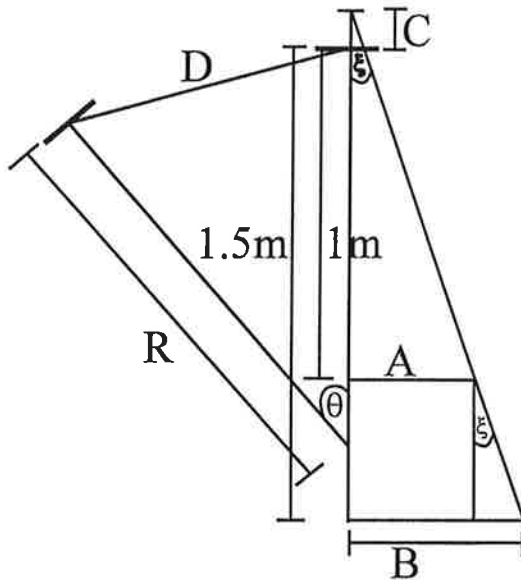
The angle θ is known as 40deg.
The distance D between the camera lenses is measured to be 81cm.
R is calculated from

$$R = \frac{D}{2 * \sin\left(\frac{\theta}{2}\right)}$$

And is in this case equal to 118.4cm.
From the horizontal scale factors calculated via the calibration measurements the full scale distances corresponding to a reading of +5V at the distances of 1m and 1.5m can be calculated. These are marked as A and B respectively.

These results were as follows.

Camera	1metre A	1.5metres B
camera 1	21.115cm	32.28cm
camera 2	17.955cm	26.815cm

The differences between these are:

camera 1	11.165cm
camera 2	8.86cm

ξ can be calculated from $\sin\xi = \dfrac{difference}{50}$

giving   ξ1 = 12.9 (sin ξ1 = 0.2233)
and   ξ2 = 10.2 (sin ξ2 = 0.1772)

The calculation of C the distance from the lens to the point of convergence of the lines of constant voltage is done using the lens diameter of 50mm:

$$C = \frac{2.5cm}{\tan \xi} \qquad \text{in cm.}$$

It is also possible to calculate C by extrapolation back from the 1m maximum distance measurement. This gives slightly a different value, but has very little effect on the path monitored for the glass, only shifting slightly the apparent starting position.

Taking camera 2 as an example:
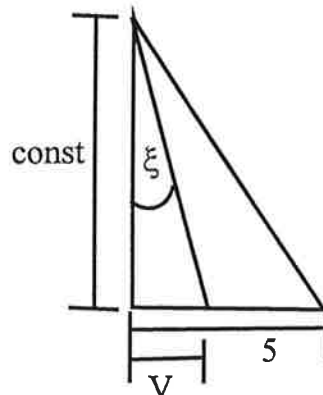
The maximum spread angle is 10.2deg and occurs at full scale ie. 5v output.

$$\sin \xi = \frac{V}{const} \qquad \text{(where V is the camera voltage)}$$

such that

$$\frac{5}{const} = \sin 10.2 \deg$$

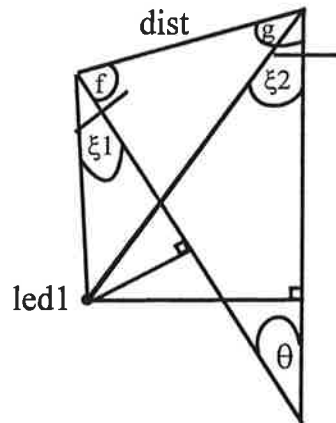Thus giving constants for both cameras, const1 and const2

Therefore ξ can be calculated from:

$$\xi = \sin^{-1}\left(\frac{V}{const}\right).$$

The distance between the two points of convergence is calculated as follows:

$$dist = \sqrt{\left((R+C_1)^2 + (R+C_2)^2 - 2*(R+C_1)*(R+C_2)*\cos\theta\right)}$$

The other angles required, f and g below (where g is the angle at vertice G), can be calculated via the sine rule:

The distances from the points of convergence (F and G) to led 1 can be calculated from:

$$G_{hyp} = \frac{\sin(f + \xi_1) * dist}{\sin(180 - (g + \xi_2) - (f - \xi_1))}$$

and

$$F_{hyp} = \frac{\sin(g + \xi_2) * dist}{\sin(180 - (g + \xi_2) - (f - \xi_1))}$$

The perpendicular distances to the camera lenses are then calculated via:

$$D_{1p} = G_{hyp} * \cos\xi_1 - C_1$$

and

$$D_{2p} = F_{hyp} * \cos\xi_2 - C_2.$$

These can be use to calculate the angles of rotation and tilt of the glass, and the position of the glass relative to the cameras.

Taking camera2 as the reference point such that towards camera2 is the Ydirection and parallel to it is the X plane. The coordinates of the glass are calculated as follows:
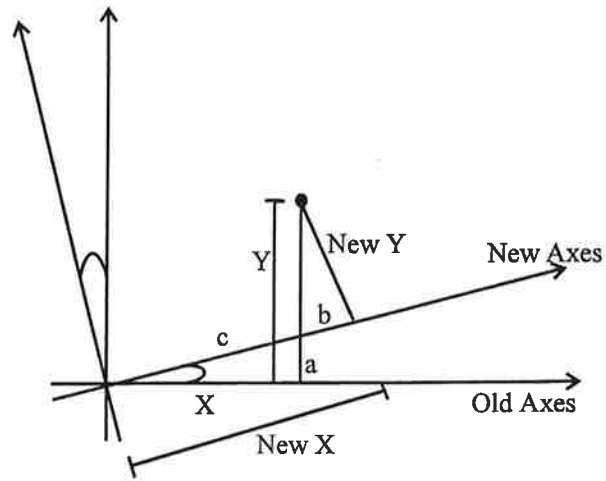
$$Y_2 = R - D_{2p}$$

$$X_2 = scalefactor_H * Xvoltage_2$$

$$Z_2 = scalefactor_V * Yvoltage_2$$

The scale factors are calculated from the calibration measurements which gave a scale factor at 1m and a value for the change in scale factor per metre away from or towards the camera.

The actual X, Y and Z coordinates of the glass where Y is in the frontal direction, X the lateral and Z the vertical are calculate as follows:

$$X = c + b = \frac{X_2}{\cos\dfrac{\theta}{2}} + Y * \cos\frac{\theta}{2}$$

$$Y = \left(Y_2 - X_2 * \tan\frac{\theta}{2} \right) * \left(\cos\left(90 - \frac{\theta}{2} \right) \right)$$

$$Z = Z_2$$

Appendix B.

B:1	Programme Guide.
B:2	Programme Information.
B:3	Virtual Instrument Plots

B:1 Programme Guide:

When the altered Postcon programme is run the user is presented with the **'Main Menu'**.
This has options labelled: **System Parameters**
Examine
Inspect
File Handler
Quit Programme.

The **'Inspect'** option has nothing to do with this study.

System Parameters contains the options:
Hardware Parameters
Programme Parameters
Test Parameters.

These are used to prompt the user to give values for some of the global variables used in the programme. Such as Maximum and Minimum test times, storage drive, output ports.
For the tests involved in this study the **'vibration'** stimulus should be selected from the **'Test Parameters'** option and then the appropriate sample rate, test duration and PRBS parameters should be entered.

Examine contains: **Initialisation**
Calibrate
Select Test
Measure
Check Measure
Calculate
Store Result
Print Result

The options **'Check Measure'**, **'Calculate'** and **'Print Result'** have no part to play in these experiments.

'Initialisation' clears the file used to store the test information during the tests and allows the user to select a file other than the default, if they wish to store more than one test on the hard drive without converting them to ASCII.
'Calibrate' allows the user to select each Analogue input in turn to insure proper operation.
'Select Test' allows the user to choose which test is to be performed. Once this has been done the computer generates the PRBS for the stimulus (it is possible to carry out the glass tests for each case if the selected test is 'the glass and eyes open test' and the other options here have only a cosmetic purpose).
The **'Measure'** option is selected when the test is to be performed and it performs the data acquisition and the output of the stimulus voltage.

On the screen when this is selected a chart is seen of the input data for some of the channels. The buttons on the screen are all labelled and there are lights to indicate that the measurement is operating properly. The **'Initialise'** button should be pressed first then the **'Start Measure'** button, to commence reading. The start button should be pressed again when the test has finished. **'Erase Measure'** can be used if something goes wrong, to redo the test. **'Exit measure'** should be selected when the test has been successfully performed. The **'Store Result'** allows the user to store the test as an ASCII text file onto either the hard drive or a floppy disk in drive a: for analysis in other software.

In the **File Handler** menu there is an option **Convert Gprob**.
This is used if there is a test that has been saved to the hard drive under a name other than the default during the tests to convert this test to ASCII and save it to a floppy disk.

B:2 Programme Information.

The software to perform the data acquisition and stimulus generation was adapted from a programme provided by Per-Anders Fransson of the ENT Clinic at Lunds University Hospital. It was written using the LabVIEW graphical programming for instrumentation package. Programming in this package involves the construction on the screen of block diagrams that show the data flow and processing involved in the programme. These are called Virtual Instruments, or VIs, and once built can be called from other VIs in much the same way as subroutines in normal text based programming.
The software was primarily required to generate and output the PRBS for the stimulus and read the voltages generated by the test equipment.
During the experiments the data is read into a circular buffer on the DAQ board then into the computer memory and spooled to disk as the test is in progress. During the test the user is provided with a chart that shows the stimulus voltage, indications of sagittal and lateral sway and three voltages representing the motion of the LED common to both cameras. Once the test has been performed the data are written to disk in the Labview binary format. The programme then offers the option to convert these data to an ASCII file for storage either on the hard drive or to floppy disk, for analysis in different software.

Descriptions of the important alterations and additions to the programme are provided below along with a description of its operation:
Menus and menu options to enable the appropriate tests to be selected and performed were added to those already in the software for the other tests performed in the clinic.
The method of saving data was converted from remote saving on the server, to onto the hard drive or floppy disk drive of the computer being used to perform the tests. This was necessary due to the absence of an ether net connection.
A few bugs in the programme had to be sorted. Primarily that the software as it stood originally did not read anything from the DAQ board of the computer. This was fixed by introducing a new initialising procedure into the programme. This new procedure also took account of the increased number of input channels (from seven to fifteen) required to receive data from the SELSPOT system as well as from the force platform.
The main problem encountered with the programme was that the output buffer on the AD board could only store an output sequence long enough for a test length of 90s at a sample rate of 25 Hz. This problem was overcome by changing the way the stimulus is stored in and output from the computer. The programme generates the PRBS for the stimulus according to parameters that the user is prompted for. This sequence is then searched through and a new array is constructed that contains information about when the sequence changes and the values to which it changes. So, instead of writing the entire sequence to the output at the start of the

test, the programme compares the present test time with that for the next stimulus change and writes the appropriate value to the output and holds it constant until the next change.

The performance of the measurement part of the programme was improved by weighting the time allocation of the computer more towards the acquisition of data than the user 'front end'. The software now only checks for new commands four times a second. This can be changed to as long as is required but four times a second seems to give adequate performance without incurring overly long delays when trying to select any button on the screen.

Some of the main VIs used in the software follow along with a summary of their operations and purposes.

RPBS.VI
Generates the array containing the voltage values for the stimulus according to a Pseudo Random Binary Sequence, the parameters of which the user has provided.

STIMC2.VI
Searches through the array generated by RPBS.VI for any changes in voltage. When a change is detected the value to which it changes is recorded in a new array along with the index for the point in the array where the change occurs.

RMINIT.VI
This VI contains the initialisation procedure for the measurement part of the programme. It assigns all the initial values to the required global variables and clears the file used to store the test data if it already exists.

Rinituns.VI
This VI is a subVI of RMINIT. This controls the configuration of the analogue input and output of the DAQ board.

rm2.VI
This is the part of the programme that controls the output of the stimulus sequence and the recording of the test data. All the user commands have been assigned to local variables enabling them to be contained in a while loop separate from the part of the software performing the data acquisition. This loop runs in parallel with the main section and the inclusion of the timer in it enables the computer to spend the majority of its time reading in the data.

MSTORE.VI
This is the VI that updates the test time and spools the data that have been recorded to the hard drive while the test is in progress.

CONDADI.VI
This VI controls the output of the stimulus voltage while the test is in progress. It checks whether the test time is correct for the next update in the stimulus and, if it is, calls AOUPDAT.VI
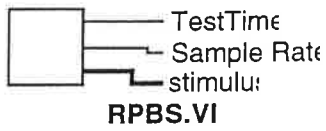
AOUPDAT.VI
When this VI is called it writes the appropriate value of output voltage to the DAQboard according to the stimulus sequence generated earlier. It then increases the index to the stimulus sequence array and writes the value for the next change in stimulus to a global variable so that CONDADI can be used to call this VI when the next change in stimulus is required.
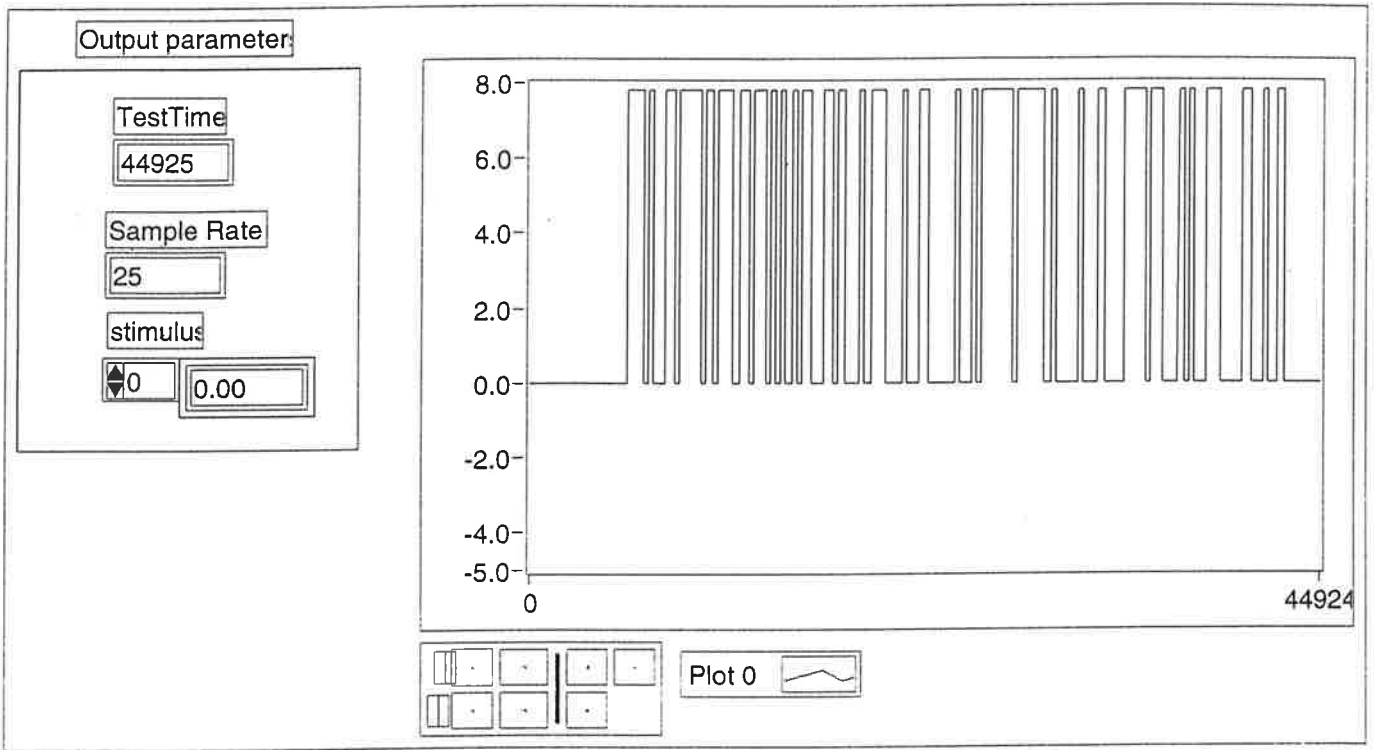
B:3 Virtual Instrument Plots:

1. RPBS.VI
2. STIMC2.VI
3. RMINIT.VI
4. Rinituns.VI
5. rm2.VI
6. MSTORE.VI
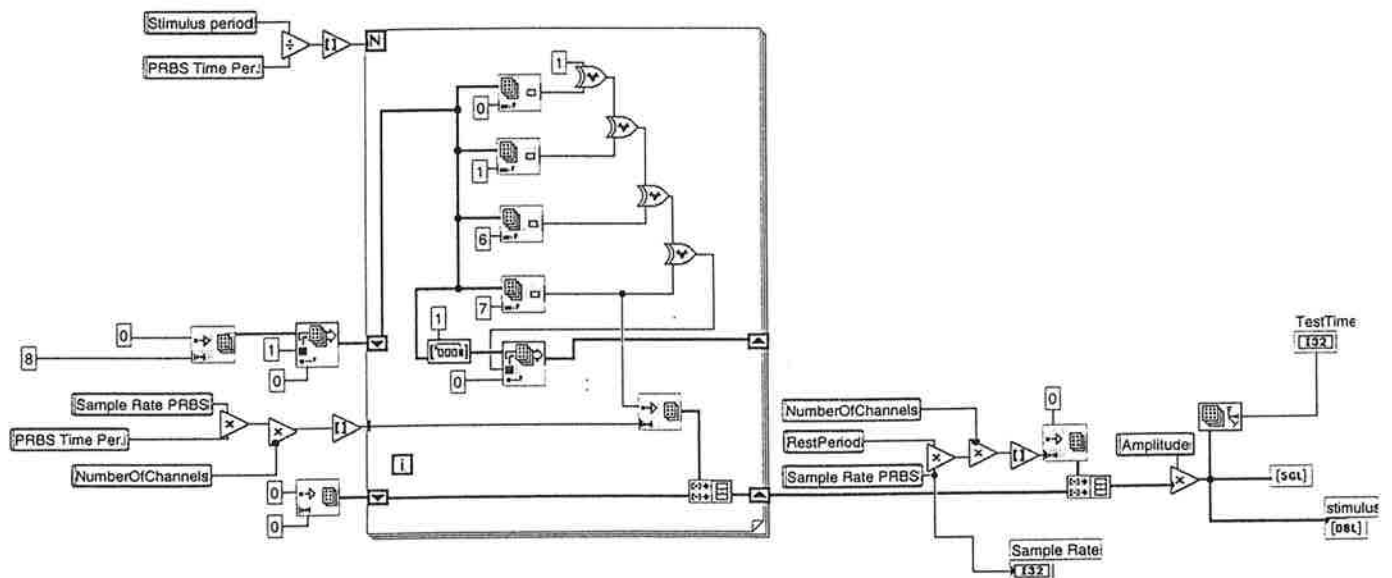7. CONDADI.VI
8. AOUPDAT.VI
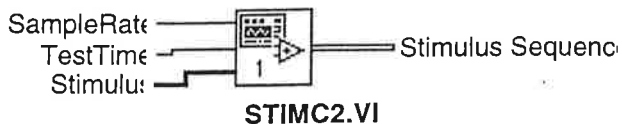
RPBS.VI
07/25/95 10:16 AM

Connector Pane

RPBS.VI

Front Panel

Block Diagram
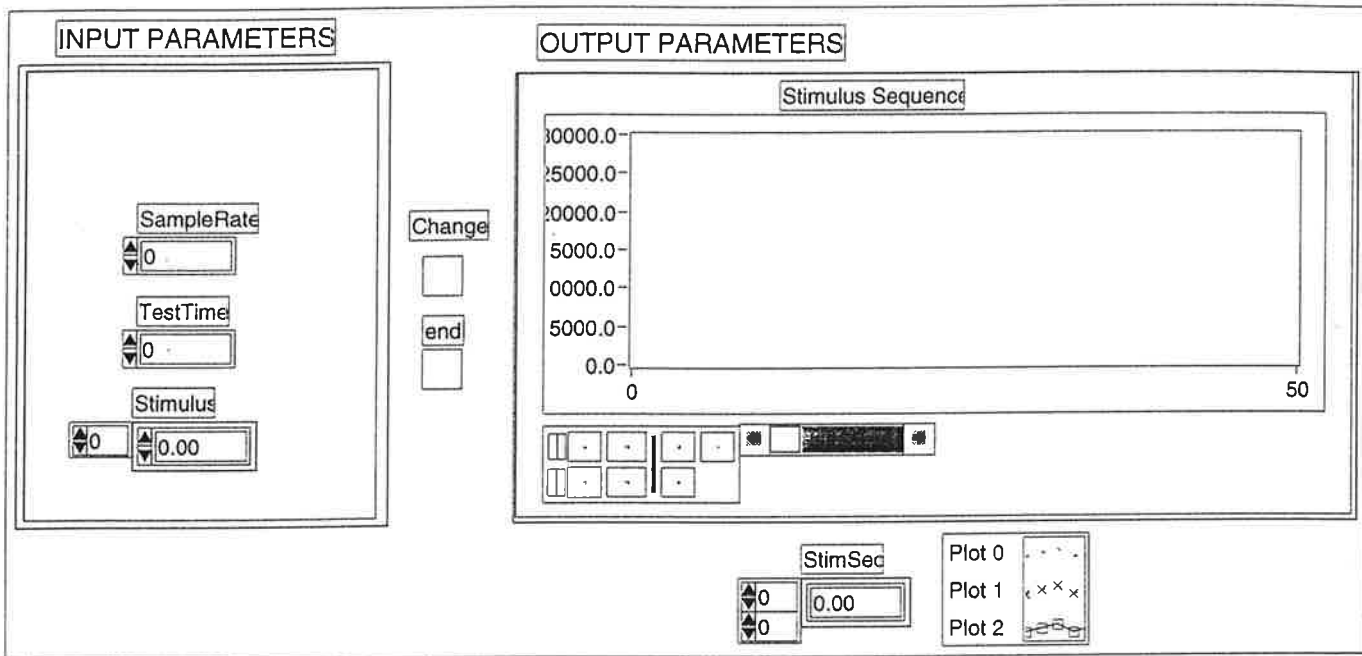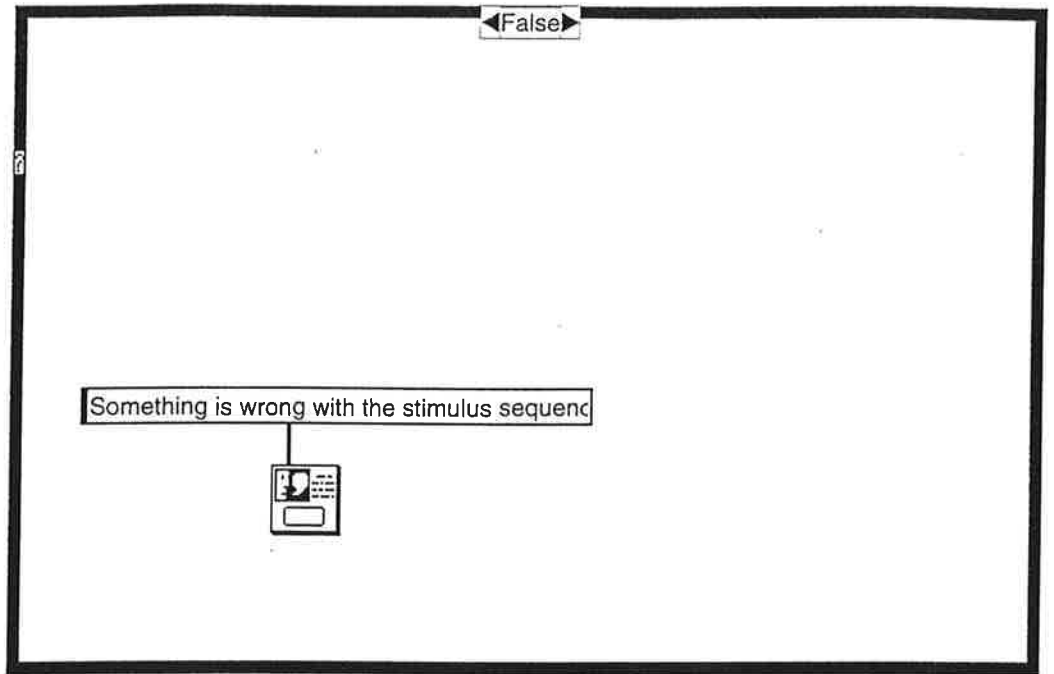
STIMC2.VI
09/10/95 03:11 PM

Connector Pane

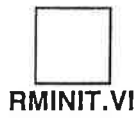SampleRate ─────
TestTime ──────   ───── Stimulus Sequence
Stimulus ──────

STIMC2.VI

Front Panel

INPUT PARAMETERS

SampleRate
0

TestTime
0

Stimulus
0   0.00

Change

end

OUTPUT PARAMETERS

Stimulus Sequence

30000.0
25000.0
20000.0
15000.0
10000.0
5000.0
0.0
0   50

StimSeq
0
0   0.00

Plot 0
Plot 1
Plot 2

Block Diagram

◀ True ▶

TestTime
I32

[SGL]
Stimulus

search for next change in stimulus. Then store the
new value of stimulus and the index of the array
when it happens

0

0.00
SGL
SGL

end
TF

Stimulus
Sequence
[SGL]

StimSeq
[SGL]

SampleRate
I32

Change
TF

STIMC2.VI
09/10/95 03:11 PM

◀False▶

Something is wrong with the stimulus sequence

RMINIT.VI
09/10/95 02:54 PM

Connector Pane

RMINIT.VI
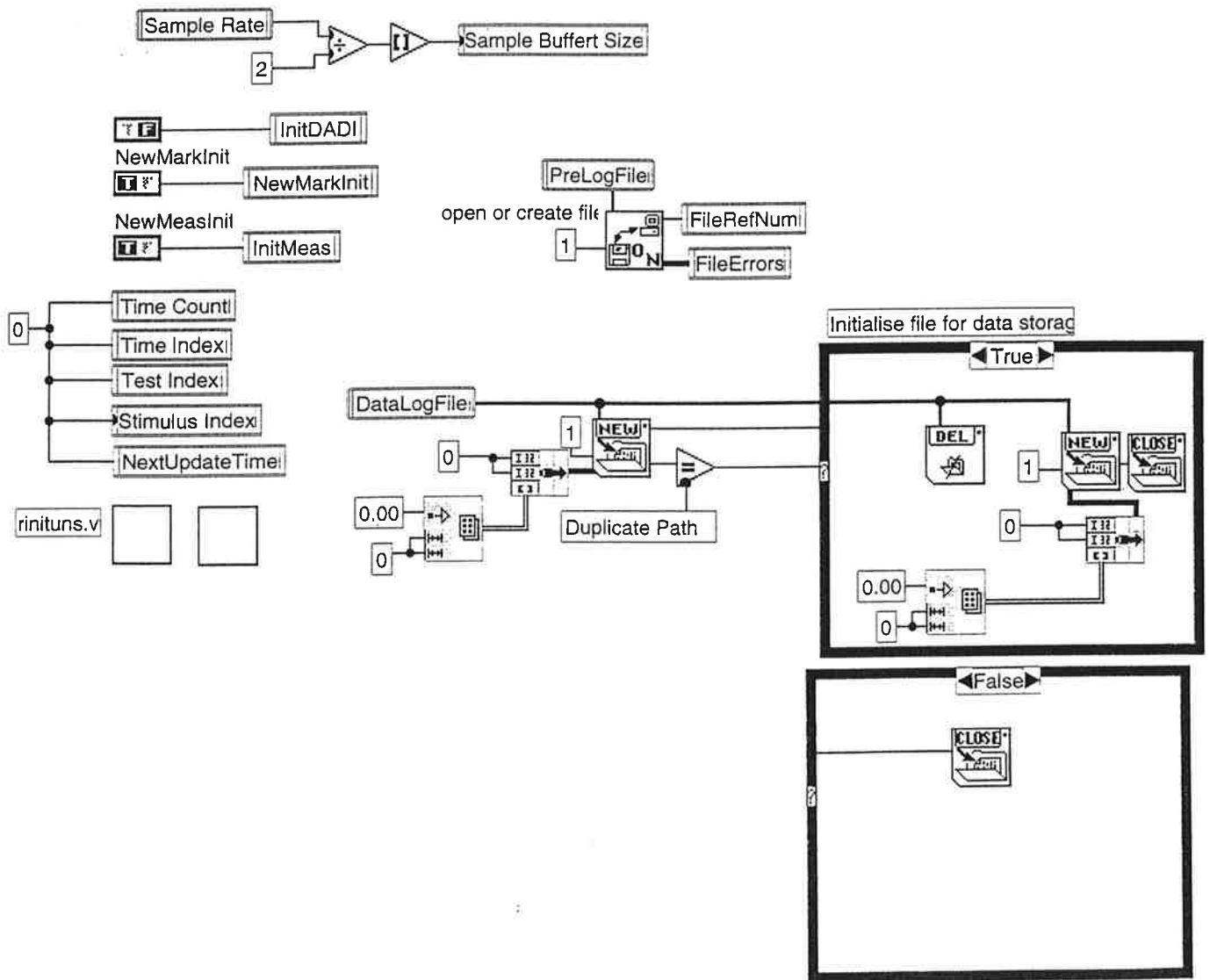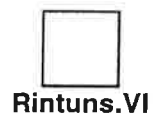
Front Panel

MEASURE

Block Diagram

Rintuns.VI
09/10/95 02:53 PM

Connector Pane

Rintuns.VI

Front Panel

MEASURE

Software setting:

Buffer size in scan
2000

Hardware setting:

input limits
(no change)
0

high limi
10.00

low limi
-10.00

Interchannel Delay (secs)
(-1:hardware default)
2.50E-3

counter lis:
0   2

Block Diagram

Initialise DAQ board for input and outp

Input ADChannels

Device
1

input limits
(no change)

Continuous Aqu
0

TaskIdAnaIn

Device
1

TaskIdAnaOut

errorDAna

counter lis:
[abc]

Control
1   2
6   123

AI
CONFIG

AI
START
1

AO
CONFIG

Clock
Config
1

Buffer size in scan:
I32

Interchannel Delay (secs)
(-1:hardware default)
SGL

Output DAChannel

0

1000.00

NumberOfChannels

NumberOfChannels

Sample Rate

rm2.vi
09/10/95 02:49 PM

Connector Pane

Start Measure ———

rm2.vi
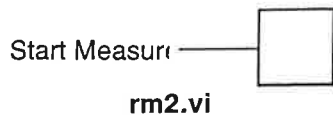
Front Panel

Software settings

Scan backlog
0

MEASURE

data

0.00

Exit

Start

Erase

Init

Plot

Stimulus

Postugrafic Test

nitiat

Erase Measure

xit Measur

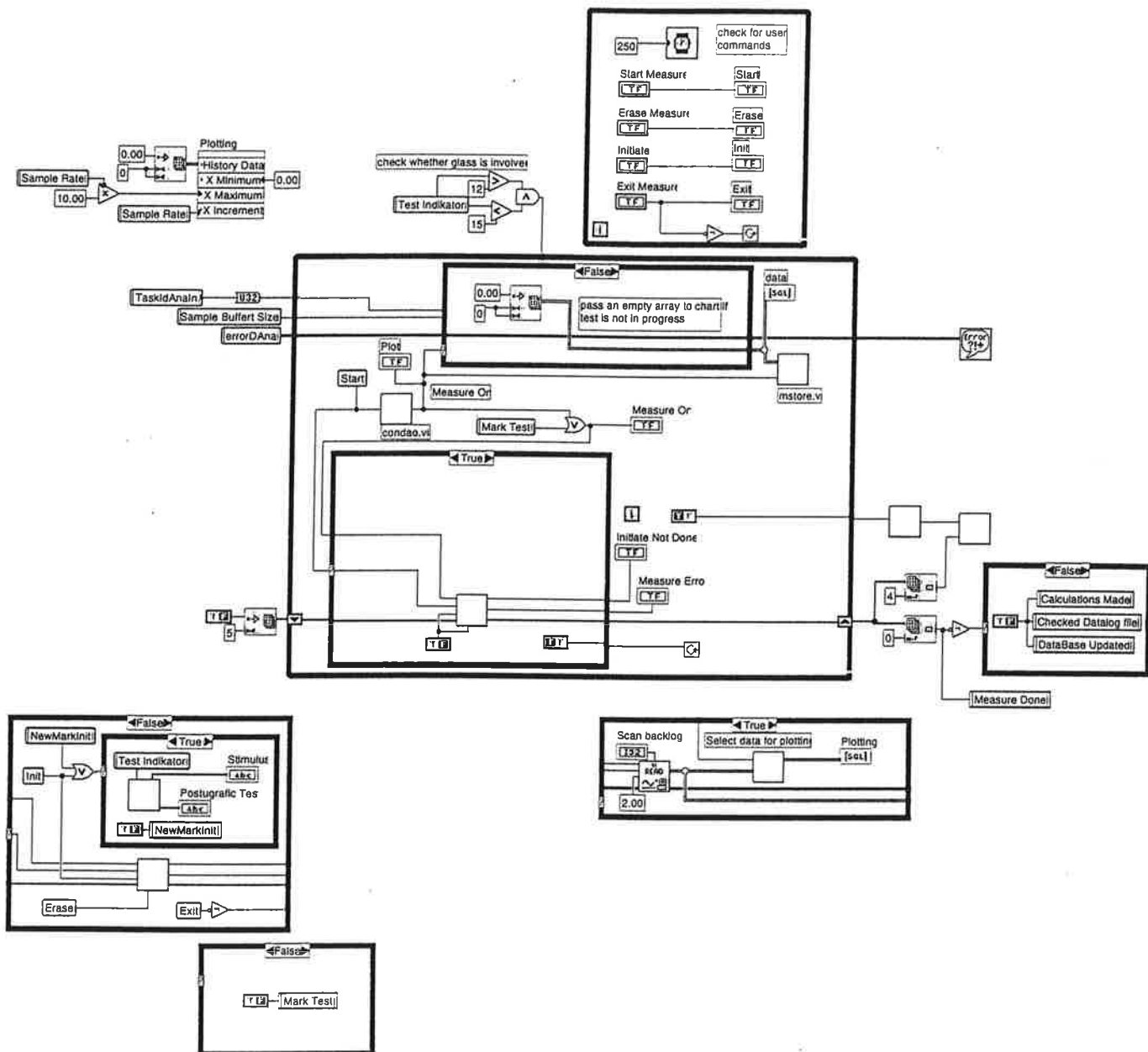tart Measur

Measure Error   Initiate Not Done

Measure On

Stimulus
Mx
My
C1 X1
C1 Y1
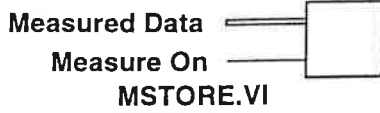C2 X1

rm2.vi
09/10/95 02:49 PM

Block Diagram

MSTORE.VI
09/10/95 02:41 PM

Connector Pane

Measured Data ──
Measure On ──
MSTORE.VI

Front Panel

Input Parameter

Measured Data

0
0   0.00

Measure On

OFF

Block Diagram

◄True►

Time Index ──────────── +1 ────────

Measured Data
[SGL]

FileRefNum
[SGL]
FileErrors

FileErrors

Measure On
TF

spool data to disk if
test is in progress

◄False►

mark the
start of a
test

Mark Test

Time Index

◄False►

◄True►

0 ── +1 ──

FileRefNum [SGL]
FileErrors

T F Mark Test   FileErrors

Test Indikator +1 ─ Test Index
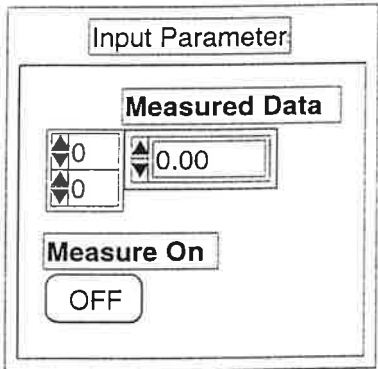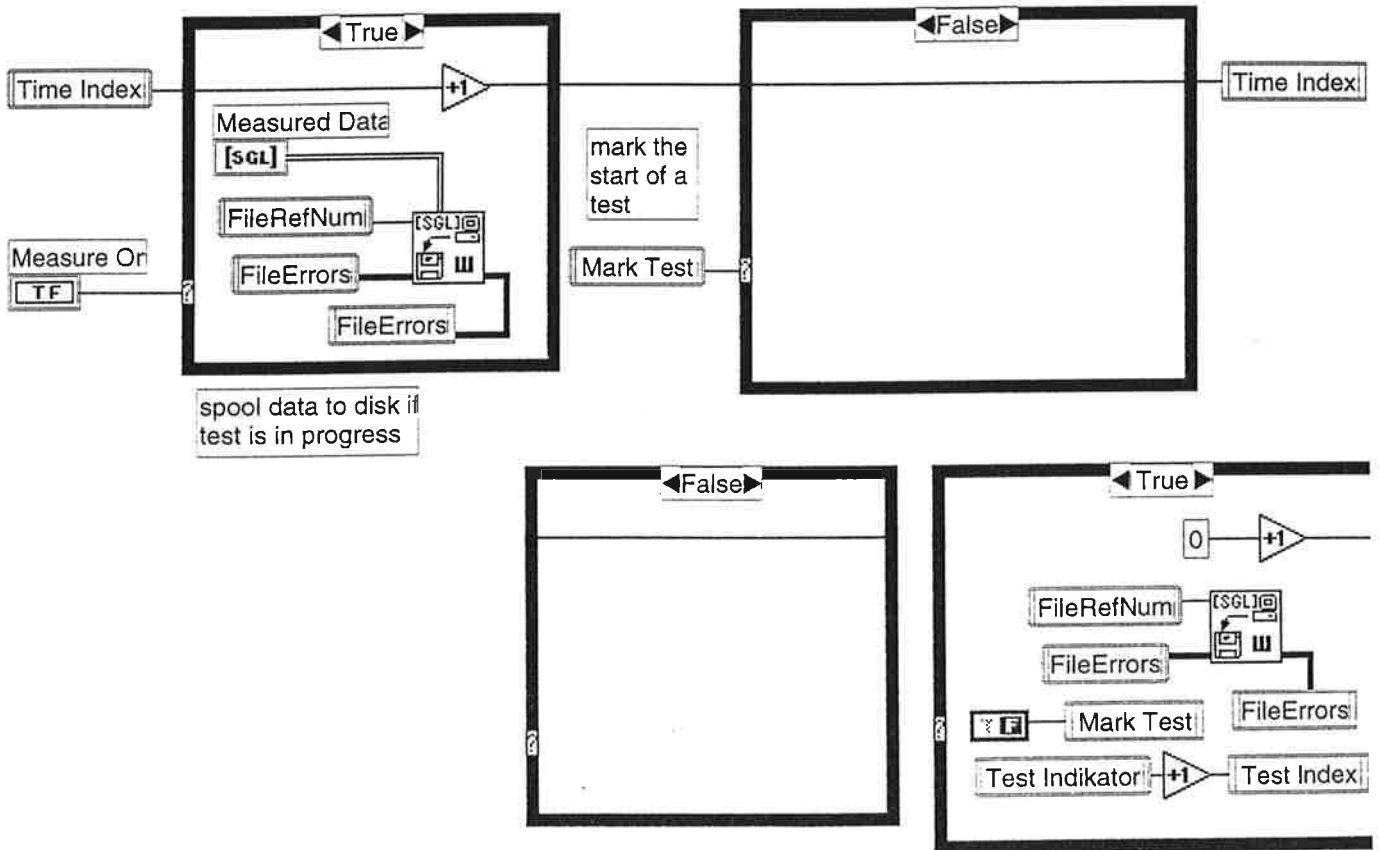
CONDADI.VI
07/25/95 01:20 PM

Connector Pane

Start Measure ——☐—— Measure On

CONDADI.VI

Front Panel

Input Parameter   Output

Start Measure   **Measure On**

OFF
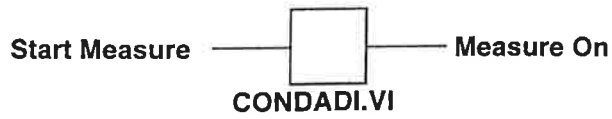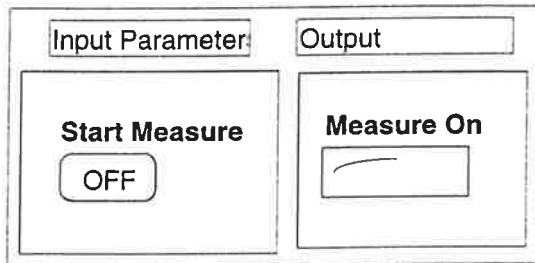
CONDADI.VI
07/25/95 01:20 PM

Block Diagram

◄True►

Time Count
Test Time

Measure Or
TF

Start Measure
TF

◄True►

Sample Buffert Size
NumberOfChannels

Time Count

NextUpdateTime

check test time
for whether
stimulus
should be

◄True►

write the
appropriate value to
the output port

1

◄False►

InitMeas

◄True►

2

InitDADI

InitMeas

◄False►

◄False►

CONDADI.VI
07/25/95 01:20 PM

◀False▶

◀True▶

0 ─ Time Count

1

InitDADI

InitDADI

InitMeas

0

◀False▶
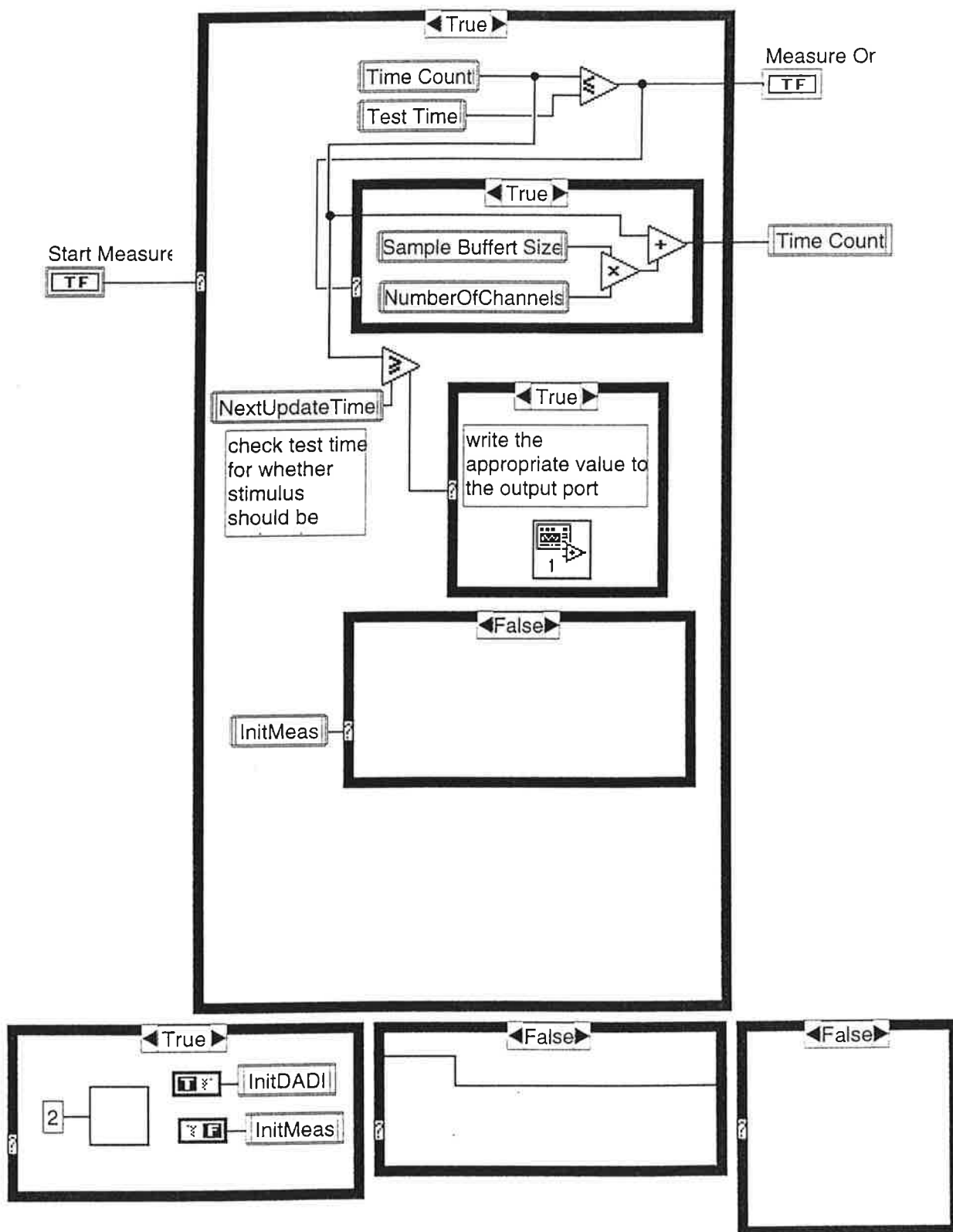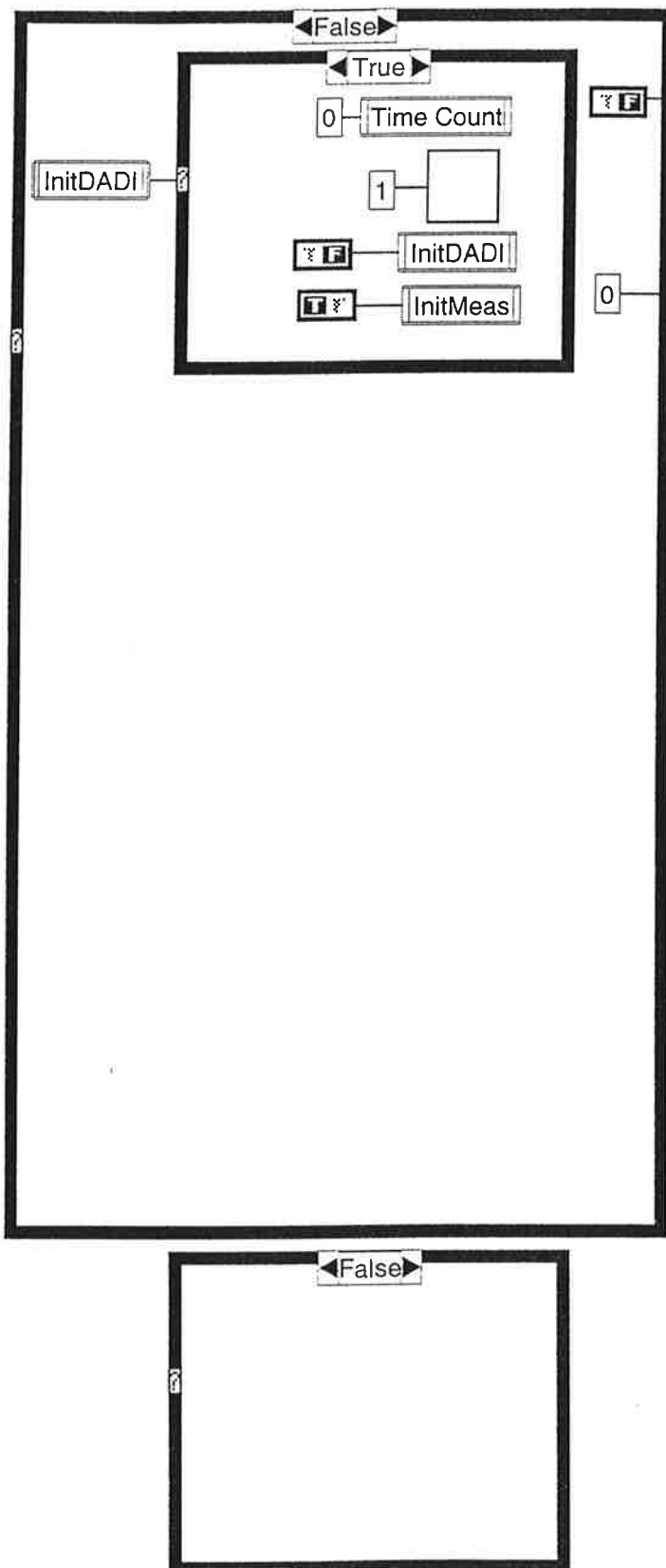
AOUPDAT.VI
07/25/95 12:47 PM

Connector Pane
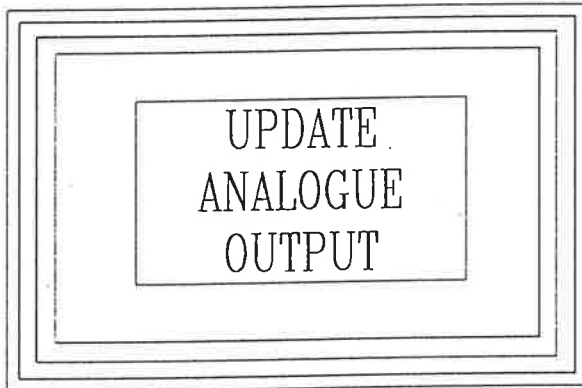
AOUPDAT.VI

Front Panel

UPDATE
ANALOGUE
OUTPUT

Block Diagram

Stimulus Sequence

Stimulus Index

Stimulus Index

NextUpdateTime

TaskIdAnaOut

Single
Update

C:2 Example plots from MATLAB analysis
The following plots were all taken from test subject 7 in the eyes open with glass test.

Swaypath plot: indicating the. motion of the subject's centre of gravity
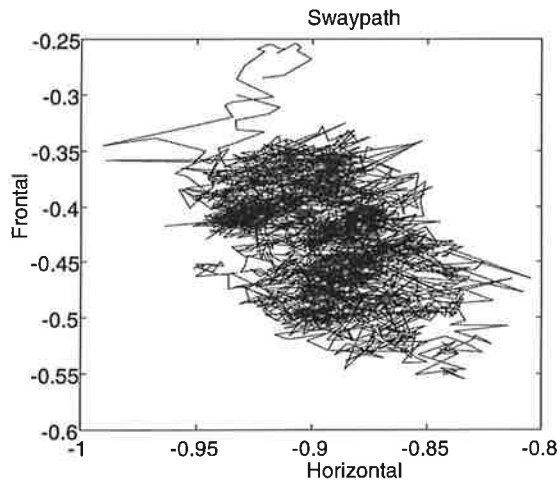
Glass path (from above). Showing the motion of the glass in the horizontal plane (in m).

Glass path (from the side)
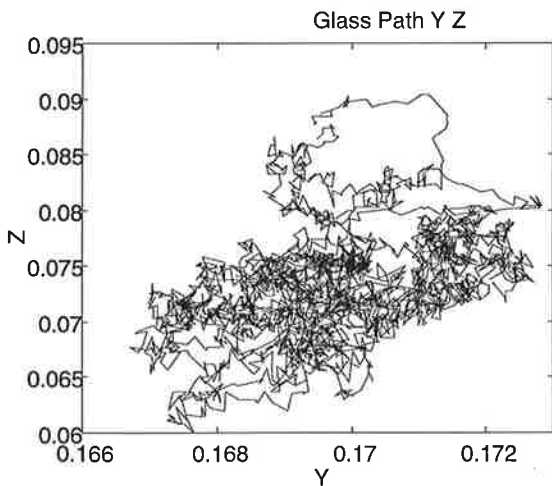
Glass path (from the front)
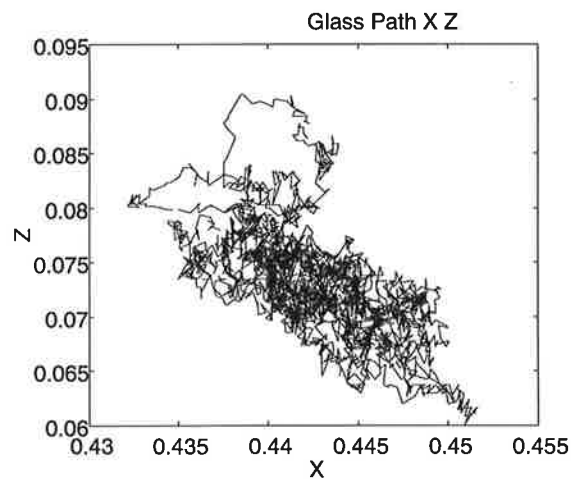
Example Glass Movement Spectrum
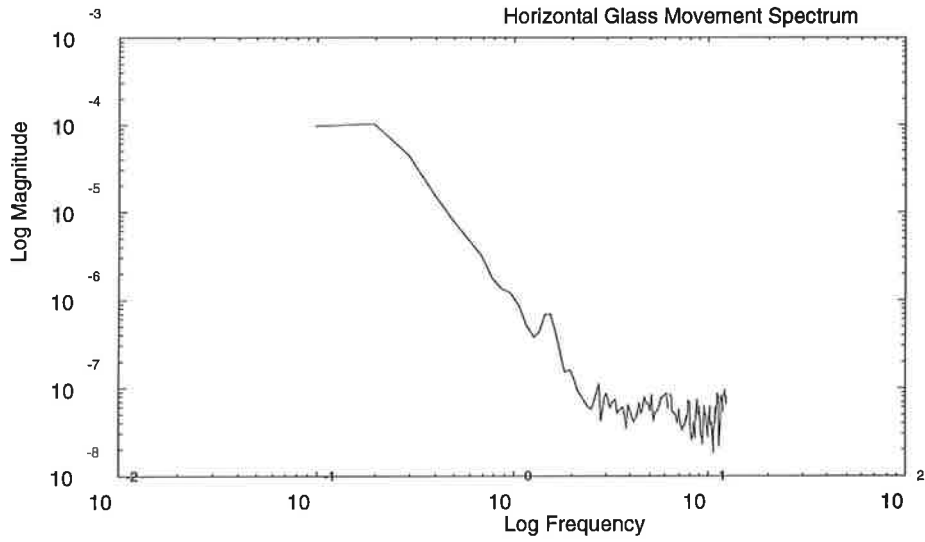
Example of saggittal torque
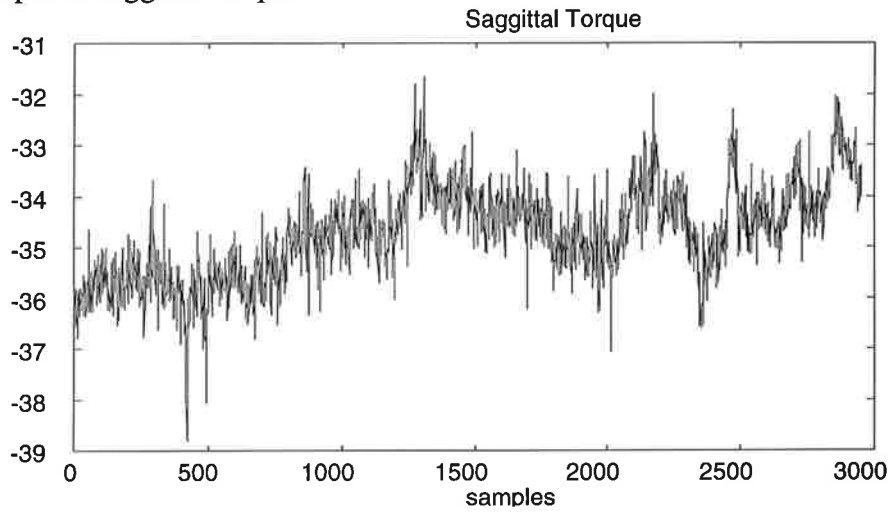
Example of the input voltage to the vibrators.
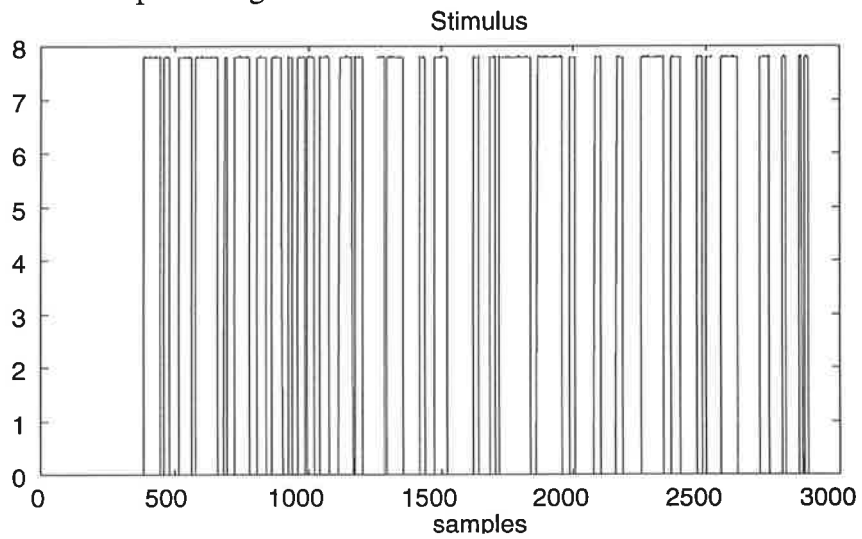
Appendix C

C:1 Explanation of MATLAB m-files
C:2 Example plots from MATLAB analysis
C:3 Transcripts of MATLAB m-files

C:1 Explanation of MATLAB m-files

The function **glasscoord.m** performs the calculations presented in appendix A to calculate the X, Y and Z coordinates of LED1. It also has the facility to return the perpendicular distances to each camera should this be required to calculate the angular orientation of the glass.

The function **gpsd.m** calculates and plots the power spectral density of the glass signals for each plane of motion along with that of the stimulus.

The function **swpath.m** uses the voltages from the force platform to calculate the swaypath of the test subject.

The function **swvel.m** uses the swaypath vectors to calculate the sway velocity of the test subject.

The function **gcompare.m** takes the data from the glass for both the eyes open and eyes closed tests and calculates their X,Y and Z coordinates, then plots them after removal of the mean values. After this it plots the power spectrum for each plane of motion for the eyes open condition against that of the eyes closed.

The function **gtana.m** takes the data from all the tests for one subject then calculates the sagittal and lateral torque variances, the variance of the sway velocity, the variance of the glass velocity, the variance of the resultant sway vector and the variance of the resultant glass vector for the rest period and after the onset of stimulus.

The other two m-files presented were provided by Per-Anders Fransson for the analysis of the force platform data. The first calculates the swiftness, stiffness and damping parameters. The second, **transfer.m**, takes the force platform voltages and converts these into the actual forces required.
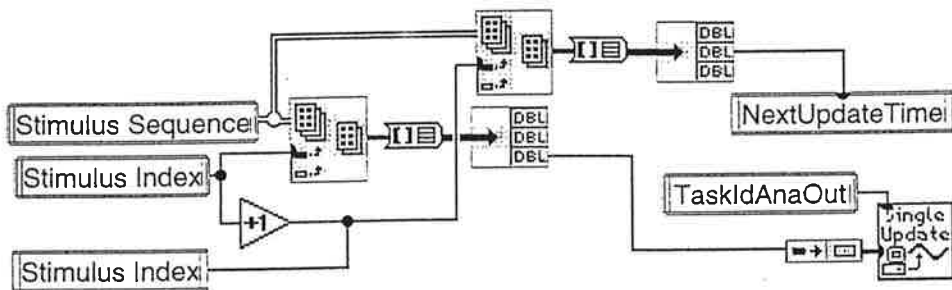
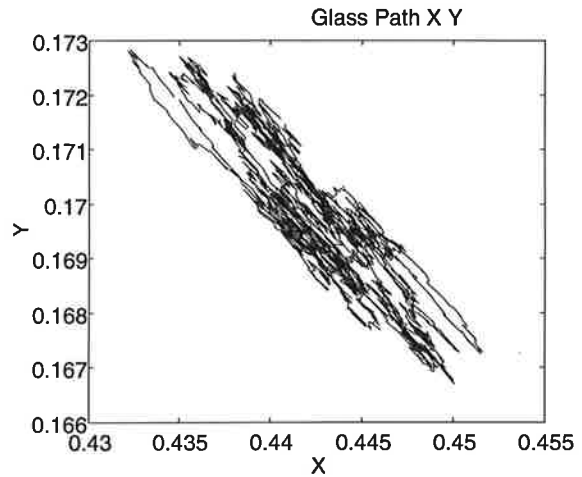## C:2 Example plots from MATLAB analysis
The following plots were all taken from test subject 7 in the eyes open with glass test.

Swaypath plot: indicating the. motion of the subject's centre of gravity

Glass path (from above). Showing the motion of the glass in the horizontal plane (in m).
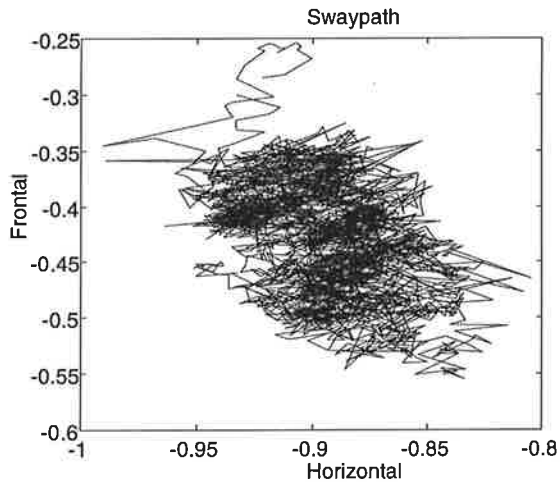

Glass path (from the side)
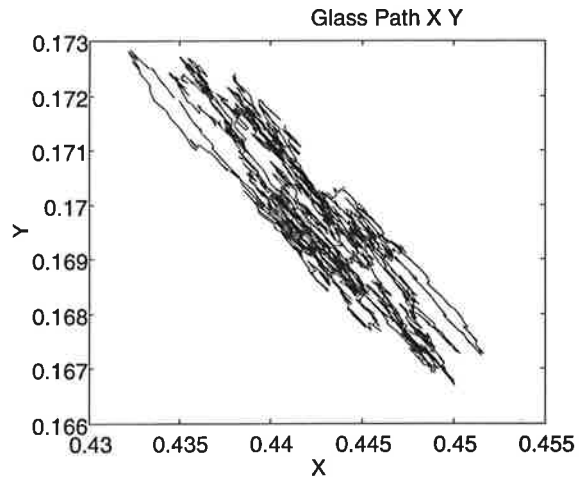
Glass path (from the front)

Example Glass Movement Spectrum

Horizontal Glass Movement Spectrum

Example of sagittal torque

Saggittal Torque
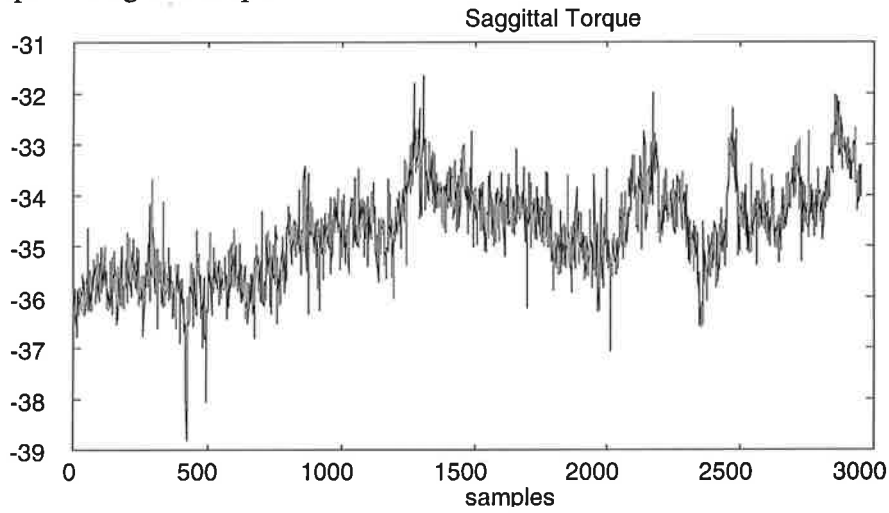
Example of the input voltage to the vibrators.

Stimulus
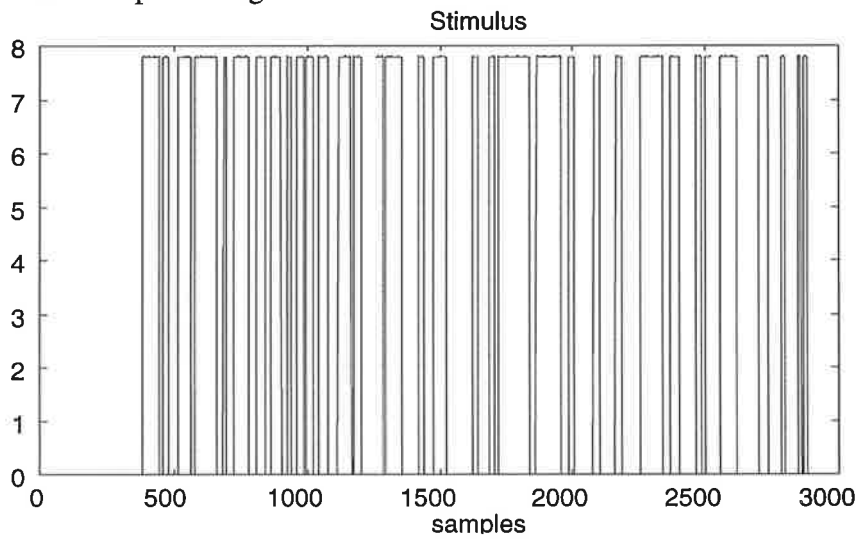
Appendix C:3

M-files for the analysis of data in MATLAB.

```
function
[X ,Y, Z,stim, d1p,d2p]=glasscoord(datain,lo,hi);
%[X Y Z stim d1p d2p]=glasscoord(datain,lo,hi);
%
%This function takes the glass voltage data
%and converts it into X,Y and Z coordinates
%in metres. The origin is the 0volts point of
%convergence between the cameras.
data = datain(lo:hi,:);
x1=data(:,8);
x2=data(:,12);
y2=data(:,13);
stim =data(:,7);
thet=40*pi/180;        %angle between the cameras
d = .81;               %distance between the camera
lenses
r = d/(2*sin(thet/2)) ;%distance from camera to
origin

%scale factors at 1metre in metres per volt
sf1v=0.04538;
sf2v=0.04308;
sf1h=0.04223;
sf2h=0.03591;

%change in scale factor per meter
delta1v=0.05;
delta2v=0.03;
delta1h=0.045;
delta2h=0.035;

%fullscale horizontal distances at a:1 and b:1.5
meters.
f1a=0.21115;
f1b=0.3228;
f2a=0.17995;
f2b=0.26815;

%max spread angles for cameras
max1 = asin((f1b-f1a)/.5);
max2 = asin((f2b-f2a)/.5);

%distance from camera lens to point of
convergence of camera voltages
C1=(0.025/tan(max1));
C2=(0.025/tan(max2));

%distance between points of convergence
dist = sqrt((r+C1).^2 + (r+C2).^2 -
2*(r+C1)*(r+C2)*cos(thet));

%angles in triangle of origin and points of
convergence
g = asin(sin(thet)*(r+C1)/dist);
f = asin(sin(thet)*(r+C2)/dist);
```

```
%constants to calculate angles from the voltage
measurements
%to the points of convergence
const1=5/sin(max1);
const2=5/sin(max2);

%angles from leds to points of converence (+ve for
+ve voltage, etc.)
zeta1=asin(x1/const1);
zeta2=asin(x2/const2);

%Straight distance from points of convergence to
led
con=(sin(180-(g+zeta2)-(f-zeta1)));
Ghyp = sin(f-zeta1)*dist./con;
Fhyp = sin(g+zeta2)*dist./con;

%perpend. distance from camera lens to plane of
the led
d1p = Ghyp.*cos(zeta1) - C1;
d2p = Fhyp.*cos(zeta2) - C2;
od1=r-d1p;
od2=r-d2p;
scaleFH = (1-d2p).*delta2h + sf2h;
scaleFV = (1-d2p).*delta2v + sf2v;

cam2x = scaleFH.*x2;
cam2z = scaleFV.*y2;

%convert these into XYZ coordinates such that
% Y=forwards Z=up X=right.
h=tan(thet/2);
p=cos(thet/2);
u=cos(.5*pi-(thet/2));
a=cam2x*h;
b=(od2-a)*p;
c=cam2x/p;

Y=u*(od2-a);
X=c+b;
Z=cam2z;

figure
subplot(221)
plot(X,Y,'b')
title('X Y plot')

subplot(222)
plot(X,Z,'g')
title('X Z plot')

subplot(223)
plot(Y,Z,'c')
title('Y Z plot')

subplot(224)
plot(dtrend(Z),'g')
hold on

s=stim/150;
plot(dtrend(Y),'c')
plot(dtrend(X),'b')
```
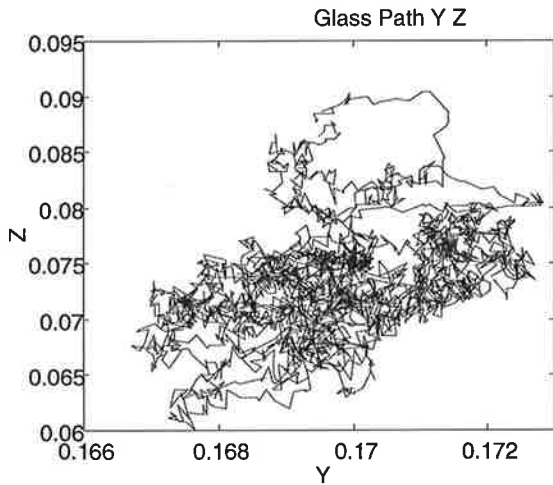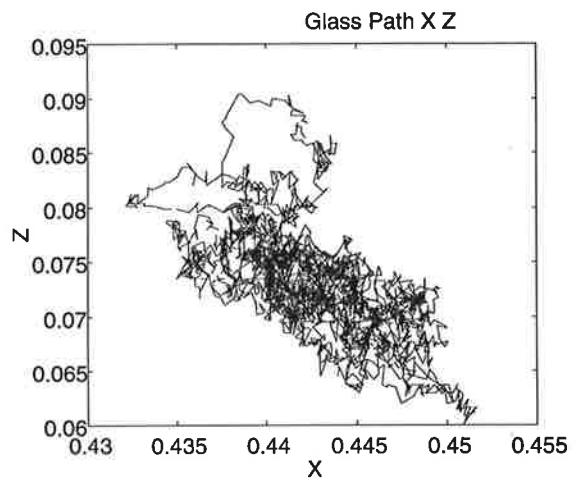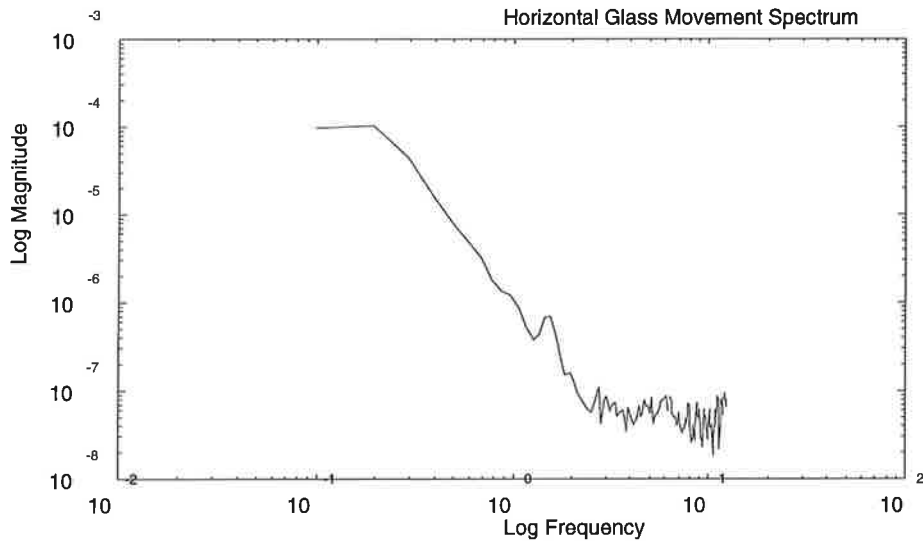
```matlab
plot(dtrend(s),'y')
title('Normalised Plot: X:b Y:c Z:g Stim:y')
hold off
```

function [pX ,pY, pZ,pstim,f]=gpsd(X,Y,Z,stim);
```matlab
%function [pX ,pY, pZ,pstim,f]=gpsd(X,Y,Z,stim);
%This calculates the power spectrum of the glass
signals.
%The signals can be normalsed before using ngplot.
%

[pX,f]=psd(X,[],25);
[pY,f]=psd(Y,[],25);
[pZ,f]=psd(Z,[],25);
[pstim,f]=psd(dtrend(stim),[],25);

figure
subplot(221)
loglog(f,pX)
xlabel('Log Freq.')
ylabel('Log Magnitude.')
title('X Position Power Spectrum.')

subplot(222)
loglog(f,pY)
xlabel('Log Freq.')
ylabel('Log Magnitude.')
title('Y Position Power Spectrum.')

subplot(223)
loglog(f,pZ)
xlabel('Log Freq')
ylabel('Log Magnitude')
title('Z Position Power Spectrum.')

subplot(224)
loglog(f,pstim)
xlabel('Log Freq')
ylabel('Log Magnitude')
title('Stimulus Voltage Power Spectrum.')
```

function [lx,ly,mx,my]=swpath(datain,lo,hi);
```matlab
%swpath(datain,lo,hi);
%                calculates the sway path of a
subject on
%                the force platform.

data=datain(lo:hi,:);
fz=transfer(data,3,lo,hi);
mx=transfer(data,4,lo,hi);
my=transfer(data,5,lo,hi);

fn=mean(fz);
lx=mx/fn;
ly=my/fn;

figure
plot(lx,ly);
title('Swaypath');
xlabel('X');
ylabel('y');
```

function swvel=swvel(lx,ly);
```matlab
%swvel=swvel(lx,ly);
%calculates the sway velocity of a subject on
%the force platform.

nn=length(lx);
for i =1:(nn-1)
                x=(lx(i+1)-lx(i));
                y=(ly(i+1)-ly(i));
                %%len2=sqrt(lx(i).^2+ly(i).^2);
                dif=sqrt(x^2+y^2);
                swvel(i)=dif/0.04;
end
```

function [Xa,Ya,Za,Sa,Xb,Yb,Zb,Sb,pxa,pya,pza,psa,fa,pxb,pyb,pzb,psb,fb]=gcompare(opendata,closeddata,lo,hi);
```matlab
%function
[Xa,Ya,Za,Sa,Xb,Yb,Zb,Sb,pxa,pya,pza,psa,fa,pxb,
pyb,pzb,psb,fb]=gcompare(opendata,closeddata,lo,
hi);
%    This function takes two sets of glass data
%    open / closed eyes. and performs in turn:
%    a: glasscoord   b: ngplot    c: gpsd.
%
%    Then compares the power spectrum of each
%    plane of glass motion.

[Xa,Ya,Za,Sa]=glcord(opendata,lo,hi);
[Xb,Yb,Zb,Sb]=glcord(closeddata,lo,hi);
[nxa,nya,nza,nsa]=ngplot(Xa,Ya,Za,Sa);
[nxb,nyb,nzb,nsb]=ngplot(Xb,Yb,Zb,Sb);
[pxa,pya,pza,psa,fa]=gpsd(nxa,nya,nza,nsa);
[pxb,pyb,pzb,psb,fb]=gpsd(nxb,nyb,nzb,nsb);

%plot power spectrums
figure;loglog(fa,pxa,'b')

hold on
title('Horizontal Glass Movement: Open:b
Closed:g.');
xlabel('Log Freq');
ylabel('Log Magnitude');
loglog(fb,pxb,'g');
figure;loglog(fa,pya,'b')
hold on
title('Frontal Glass Movement: Open:b Closed:g.');
xlabel('Log Freq');
ylabel('Log Magnitude');
loglog(fb,pyb,'g');
figure;
loglog(fa,pza,'b')
hold on
title('Vertical Glass Movement: Open:b Closed:g.');
xlabel('Log Freq');
ylabel('Log Magnitude');
loglog(fb,pzb,'g');
```

```matlab
function gtana(dataa,datab,datac,datad);
% gtana(dataa,datab,datac,datad);
%                This function will take test data
from four glass tests
%and calculate.
%A:saggittal and lateral torque variances for before
and after the onset of stimulus.
%B:variance of sway velocity for before and after
the onset of stimulus
%C:variance of glass velocity for before and after
the onset of stimulus
%D:variance of resultant sway vector for before and
after the onset of stimulus
%E:variance of resultant glass vector for before and
after the onset of stimulus

[xa,ya,saga,lata]=swpath(dataa,1,3000);
[xb,yb,sagb,latb]=swpath(datab,1,3000);
[xc,yc,sagc,latc]=swpath(datac,1,3000);
[xd,yd,sagd,latd]=swpath(datad,1,3000);
disp('Swaypaths Calculated')
va=swvel(xa,ya);
vb=swvel(xb,yb);
vc=swvel(xc,yc);
vd=swvel(xd,yd);
disp('Sway velocities calculated')
resa=sqrt(xa.^2+ ya.^2);
resb=sqrt(xb.^2+ yb.^2);
resc=sqrt(xc.^2+ yc.^2);
resd=sqrt(xd.^2+ yd.^2);
disp('Resultant Sway Vectors Calculated')
[Xa,Ya,Za]=glcord(dataa,1,3000);
[Xb,Yb,Zb]=glcord(datab,1,3000);
disp('Glass Coordinates Calculated')
gva=gvel(Xa,Ya,Za);
gvb=gvel(Xb,Yb,Zb);
disp('Glass Velocities Calculated')
gresa= sqrt(Xa.^2+ Ya.^2+ Za.^2);
gresb= sqrt(Xb.^2+ Yb.^2+ Zb.^2);
disp('Glass Resultant Vectors Calculated')
disp('all raw data has now been
processed....covariance calculations now in
progress.')

disp('Saggittal Torques')
disp('A           B           C           D')

nn=length(saga);
preA=cov(saga(1:380));
postA=cov(saga(381:nn));
preB=cov(sagb(1:380));
postB=cov(sagb(381:nn));
preC=cov(sagc(1:380));
postC=cov(sagc(381:nn));
preD=cov(sagd(1:380));
postD=cov(sagd(381:nn));
disp('pre')
disp([preA,preB,preC,preD])
disp('post')
disp([postA,postB,postC,postD])
pause
disp('Lateral Torques')

disp('A           B           C           D')
preA=cov(lata(1:380));
postA=cov(lata(381:nn));
preB=cov(latb(1:380));
postB=cov(latb(381:nn));
preC=cov(latc(1:380));
postC=cov(latc(381:nn));
preD=cov(latd(1:380));
postD=cov(latd(381:nn));
disp('pre')
disp([preA,preB,preC,preD])
disp('post')
disp([postA,postB,postC,postD])
pause
disp('Sway Velocity')
disp('A           B           C           D')
nn=length(va);
preA=cov(va(1:380));
postA=cov(va(381:nn));
preB=cov(vb(1:380));
postB=cov(vb(381:nn));
preC=cov(vc(1:380));
postC=cov(vc(381:nn));
preD=cov(vd(1:380));
postD=cov(vd(381:nn));
disp('pre')
disp([preA,preB,preC,preD])
disp('post')
disp([postA,postB,postC,postD])
pause
disp('Glass Velocity')
disp('A           B')
nn=length(gva);
preA=cov(gva(1:380));
postA=cov(gva(381:nn));
preB=cov(gvb(1:380));
postB=cov(gvb(381:nn));
disp('pre')
disp([preA,preB])
disp('post')
disp([postA,postB])
pause
disp('Resultant Sway vector')
disp('       A           B           C
        D')
nn=length(resa);
preA=cov(resa(1:380));
postA=cov(resa(381:nn));
preB=cov(resb(1:380));
postB=cov(resb(381:nn));
preC=cov(resc(1:380));
postC =cov(resc(381:nn));
preD=cov(resd(1:380));
postD=cov(resd(381:nn));
disp('pre')
disp([preA,preB,preC,preD])
disp('post')
disp([postA,postB,postC,postD])
pause
disp('Resultant Glass Vector')
disp('       A           B')
nn=length(gresa);
```

```
preA=cov(gresa(1:380));
postA=cov(gresa(381:nn));
preB=cov(gresb(1:380));
postB=cov(gresb(381:nn));
disp('pre')
disp([preA preB])
disp('post')
disp([postA postB])
pause
disp('Calculation complete.')
```

% Function for calculation of parametric identification vibration
% P-A Fransson 930216

```
clc
fil=input('File name ?  ','s');

disp(' ')
disp('The file is loaded')

eval(['load',' ',fil])
disp(' ')

nfil=fil(1:length(fil)-4);
eval(['d=',nfil,';']);

nn=length(d(:,4));
z=transfer(d,4,375,nn);          %remove rest
period
z=dtrend(z);
```

```
% Rutin f'r ber„kning av parametrarna stiffness,
swiftness och
% damping.
% Micael Åkesson 87-12-15
% Rev P-A Fransson 930216

h=0.04;
th=armax(z,[3 3 2]);
[Ad,Bd,Cd,Dd,Fd]=polyform(th);
[Bc,Ac]=desample(Bd,Ad,h);
swift=real(Ac(4))^(1/3);
stiff=real(Ac(3))/(swift^2);
damp=real(Ac(2))/swift;
disp(' ');
disp('Swiftness Stiffness Damping');
disp([swift,stiff,damp]);
subplot(111)
```

function z=transfer(data,index,lo,hi);

```
%TRANSFER(data,Index,lo,hi);
%
%       Makes balanceform from dataarray "data"
within data array
%       data(:,lo) to data(:,hi) into the force or
moment expected.
%       The option is selected by index:
%       1 : z=[Fx stim], 2: z=[Fy stim], 3: z=[Fz
stim],
%       4 : z=[Mx stim], 5: z=[My stim], 6: z=[Mz
stim],
%       The transform is made through a
transformation matrix
%       which comes from a tests of platform
dynamics made by
%       Olof Samuelsson.
%
%             P A Fransson 911022
%

datab=data(lo:hi,:);

%transformmatrix with F=A*S
%F=[Fx Fy Fz Mx My Mz];
%S=[Sx Sy1 Sy2 Sz1 Sz2 Sz3];

A=[1.0150 -0.0251  0.0286  0.0007 -0.0099  0.0259
   0.0106  1.0298  1.0075  0.0036 -0.0036 -0.0172
   0.0309 -0.0010 -0.0245  1.0107  1.0002  0.9950
   0.0087  0.0567  0.0480  0.1714  0.1691 -0.1796
  -0.0636 -0.0000  0.0044  0.1768 -0.1711 -0.0053
  -0.1693 -0.1359  0.1313 -0.0008 -0.0054  0.0028];

%Postcon measures the data in form s'=[Sz1 Sz2
Sz3 Sx Sy1 Sy2 stim*index]

data1(:,1)=datab(:,4);
data1(:,2)=datab(:,5);
data1(:,3)=datab(:,6);
data1(:,4)=datab(:,1);
data1(:,5)=datab(:,2);
data1(:,6)=datab(:,3);
stim=datab(:,7);
```

```
% Select force or moment
% The forces is specifyed by the schedual below
with z-receivers marked
%
%     *     platform
%  *  *
%
%     *
%  * *                   *
%     *           **  * Fx
%     *   Fy + Mx       *
```

```
% ™vriga moment moturs kring axlarna dvs inte
som O. Samuelssons def.

if index==1,
```

```matlab
  Fx=-A(1,:)*data1';
% Fx=Fx-mean(Fx);
  z=[Fx'*200 stim];
end;
if index==2,
  Fy=-A(2,:)*data1';
% Fy=Fy-mean(Fy);
  z=[Fy'*200 stim];
end;
if index==3,
  Fz=A(3,:)*data1';
% Fz=Fz-mean(Fz);
  z=[Fz'*400 stim];
end;
if index==4,
  Mx=-A(4,:)*data1';
  -A(4,:);
pause
% Mx=Mx-mean(Mx);
  z=[Mx'*400 stim];
end;
if index==5,
  My=A(5,:)*data1';
% My=My-mean(My);
  z=[My'*400 stim];
end;
if index==6,
  Mz=A(6,:)*data1';
% Mz=Mz-mean(Mz);
  z=[Mz'*400 stim];
end;
```

Appendix D.

Data.

Calibration of SELSPOT

The following voltages are representative of a distance of 10cm.
The measurements were made using a spirit level wih the markers placed on it at distances of 1m and 1.5m, for both the horizontal and the vertical planes.

Camera	1m vertical	1m horizontal	1.5m vertical	1.5m horizontal
camera 1	2.2035	2.368	1.4128	1.549
camera 2	2.321	2.785	1.715	1.8647

These correspond to scale factors in cm per volt of:

Camera	1m vertical	1m horizontal	1.5m vertical	1.5m horizontal
camera 1	4.538	4.223	7.078	6.456
camera 2	4.308	3.591	5.831	5.363

The increases in scale factor from 1m to 1.5m are:

Camera	Vertical	Horizontal
camera1	2.54	2.233
camera2	1.523	1.772

This represents a change per cm of:

Camera	Vertical	Horizontal
camera1	0.05	0.045
camera2	0.03	0.035

Swiftness, stiffness and damping parameters

Eyes open with glass.

Subject	Swiftness	Stiffness	Damping
1.	15.6455	16.4287	2.1558
2.	3.2990	12.6472	5.241
3.	2.2435	12.3251	6.9658
4.	2.8295	5.5427	4.5308
5.	3.551	29.5071	13.0135
6.	3.0595	11.3745	4.0743
7.	3.938	11.9344	12.067
8.	3.6345	16.8173	13.1288
9.	2.703	11.8947	6.8244

Eyes closed with glass

Subject	Swiftness	Stiffness	Damping
1.	1.6865	4.2710	4.3855
2.	5.2505	4.9111	2.7105
3.	3.3845	10.7613	5.3908
4.	1.827	3.7106	3.9490
5.	2.8615	5.9542	4.7548
6.	7.043	5.8983	3.9715
7.	5.2195	4.4582	3.7490
8.	4.725	5.0394	5.6621

9.	8.0935	3.9773	3.7666

Eyes open

Subject	Swiftness	Stiffness	Damping
1.	2.081	13.4722	7.3131
2.	7.5567	30.6125	0.5380
3.	1.5325	5.0127	3.6612
4.	10.821	29.8671	0.2522
5.	6.252	11.8668	6.1933
6.	2.233	15.4259	7.7952
7.	4.1275	14.3642	12.5477
8.	2.9048	7.4625	5.4116
9.	5.401	5.3634	5.1192

Eyes closed

Subject	Swiftness	Stiffness	Damping
1.	1.704	5.974	6.6058
2.	4.0865	8.319	3.4627
3.	4.4565	6.3275	3.8564
4.	1.86	3.4614	3.4642
5.	3.2295	4.9459	4.2229
6.	5.8195	7.02	3.4283
7.	6.039	5.3632	4.6505
8.	5.401	5.3634	5.1192
9.	1.665	5.4134	4.7343

Swiftness

	Mean	Variance	Max	Min
Glass & eyes open	4.5448	17.5998	15.6435	2.2435
Glass & eyes closed	4.4546	4.9353	8.0935	1.6865
Eyes open	4.47677	9.3769	10.8210	1.5325
Eyes Closed	3.8068	3.1510	6.0390	1.6650

Stiffness

	Mean	Variance	Max	Min
Glass & eyes open	14.2746	43.1726	29.5071	5.5427
Glass & eyes closed	5.4424	4.5865	10.7613	3.7106
Eyes open	14.8275	90.8342	30.6125	5.0127
Eyes Closed	5.7986	1.8590	8.3190	3.4614

Damping

	Mean	Variance	Max	Min
Glass & eyes open	7.5557	17.2336	13.1288	2.1558
Glass & eyes closed	4.26	0.8238	5.6621	2.7105
Eyes open	5.4257	14.2939	12.5477	0.2522
Eyes Closed	4.3938	1.0728	6.6058	3.4283

Ratio of Stimulated Variance to Rest Period Variance

A: Velocity

Subject	Sway Open	Glass Open	Sway Closed	Glass Closed
1	2.203	5.4286	1.6244	0.0689
2	1.366	2.777	1.5538	1.9375
3	1.0649	4.1786	1.7186	0.75
4	1.248	1.2105	2.79	3.622
5	2.074	7.455	1.583	9.5
6	0.987	22	1.41	32.3
7	2.556	3.556	2.507	2.777
8	1.1507	4.85	1.522	1.351
9	7.165	1.3	2.407	1.7117

B: Position

Subject	Sway Open	Glass Open	Sway Closed	Glass Closed
1.	4.667	4.257	2.304	1.205
2.	7	3.5798	6.083	15.037
3.	10.5	1.7	5	1.728
4.	1.769	1.833	10.2	3.3913
5.	8	7.462	6.83	15.8
6.	6.397	33.9	2.1595	54.5
7.	9.933	5.399	11.154	4.576
8.	5	2.99	1.381	0.758
9.	22.156	1.523	6.909	1.568

Ratio Glass/Sway Velocity variances.

Subject	Eyes open	Eyes Closed
1.	2.464	0.043
2.	2.0329	1.2468
3.	3.9239	0.4364
4.	0.96995	1.2982
5.	3.5945	6.0013
6.	22.29	22.9
7.	1.391	1.1077
8.	4.215	0.888
9.	0.181	0.711

Ratio Glass/Sway Position variances.

Subject	Eyes open	Eyes closed
1.	0.912	0.523
2.	0.5114	2.472
3.	0.162	0.3456
4.	1.0362	0.332
5.	0.9328	2.313
6.	5.2994	25.237
7.	0.5435	0.4103
8.	0.598	0.549
9.	0.0687	0.227

Torque Variances

Sagittal Torque Variance

	Glass&eyes open	Glass&eyes Closed	Eyes open	Eyes closed
1. ABCD	0.3367	0.5425	0.3319	0.2438
2. BCDA	0.7724	1.2068	1.0694	1.4055
3. CDAB	0.7704	0.7776	0.3767	0.8377
4. DABC	0.6874	1.0643	1.2903	0.9627
5. ACBD	1.4755	0.3199	0.2872	0.5210
6. BDCA	1.4284	1.5853	1.5178	1.3347
7. DCAB	1.6320	2.6410	2.9992	3.2904
8. CABD	0.7506	2.1207	0.3423	1.2768
9. DACB	0.3773	0.7813	0.1953	0.7629

Lateral Torque Variance

	Glass&eyes open	Glass&eyes Closed	Eyes open	Eyes closed
1. ABCD	1.6758	2.7644	1.4641	1.6095
2. BCDA	0.8358	2.1320	1.9907	1.9384
3. CDAB	3.5852	1.1438	1.5046	1.9334
4. DABC	2.1911	4.7044	2.7389	1.5189
5. ACBD	1.4815	0.4926	0.3810	1.1711
6. BDCA	1.3665	5.3498	2.3504	2.6551
7. DCAB	2.4461	3.4624	4.9824	4.3662
8. CABD	3.6851	9.0740	1.2535	3.9688
9. DACB	0.7092	1.2559	0.4135	1.4071

Appendix E

Suggestions for further work.

If this study were performed again I think that the vibrators used as stimulus should be less intense than the ones that were used. I believe that this would cause any changes in response of the test subjects to be due more to the inclusion of the glass and to the availiability of visual information, than to becoming familiar to the stimulus.

The second and third LEDs from the SELSPOT system although attached to the glass in the appropriate positions during the test have not been used for anything other than the calibration of the system. If the angular displacement of the glass were to be calculated it would be interesting to see if there were any relationship between, for example, the sagittal tilt of the subject and the forwards tilting of the glass. It is felt, however, that the resolution of the system is such that the angles measured would probably not be very useful, the distances between the LEDs are 28 and 35 mm and the cameras can only register changes in position of around 0.39 mm. If the angular orientation of the glass were not considered important then the LEDs could be positioned one on the glass and one on the subject's body, possibly on their center of gravity. This would give a clear indication of the glass position relative to that of the body at every instant in time, rather than comparing just their variances. This would however introduce more problems concerned with the camera placement. Trying to keep the two leds visible to both cameras while keeping the cameras close enough to have a good resolution would be very difficult and the is the possibility of the subject obscuring the body marker with their arm during a corrective movement of the glass.

The resolution of the cameras is such that, if performing the tests again, I would perform a recalibration of the cameras, using LEDs seperated by a greater distance than 10cm, for instance 30cm, for the calibration. This would reduce the effect that any errors in these measurements would have on tests and give more accurate values for the changes in scale factor.