TP 13804E

Measurement and Monitoring of the Effects of Work Schedule and Jet Lag on the Information Processing Capacity of Individual Pilots

Phase 2

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16. Abstract

Electroencephalographic (EEG) and multitasking results (MT) were recorded from Canada 3000 pilots flying between Vancouver and Europe or the South Pacific. The EEG was in the range of 35 to 45 Hz. Recordings were done approximately every three hours during flight after take-off and preceding landing. Take-off and landing patterns relative to circadian periods were plotted and individual indexes that combined MT and EEG were computed for each pilot.

The data suggest that there are important individual differences in the effect of jet lag on pilots. Periods of concern (PC), defined as those periods when MT scores were declining and 40 Hz was increasing, were related to problematic circadian periods when there had been insufficient time for adjustment after jet lag. The data also suggest it is important to consider the effects of circadian adjustments in the design of crew duty schedules and of departure and arrival times for pairings that include jet lag.

Recommendations of this phase of the study were: (1) to develop an individual multitasking index for each pilot to be used by that pilot to make an objective assessment of fatigue; and (2) to develop a multitasking procedure that can be used as an index of and countermeasure for fatigue during flights.

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16. Résumé

Des pilotes de Canada 3000 ont été soumis à des enregistrements électroencéphalographiques (EEG) et à des tests multitâches (MT) pendant qu'ils volaient entre Vancouver et l'Europe ou le Pacifique Sud. L'EEG mesurait l'activité cérébrale dans la bande gamma de 35 à 45 Hz. Ces mesures avaient lieu environ toutes les trois heures pendant la période de vol suivant le décollage et précédant l'atterrissage. Les chercheurs ont tracé des courbes des heures de décollage et d'atterrissage en fonction des périodes circadiennes et ils ont établi, pour chaque pilote, des indices personnalisés de fatigue issus de la combinaison des résultats aux tests MT et des enregistrements EEG.

Les données recueillies révèlent d'importantes différences individuelles en ce qui a trait aux effets du décalage horaire sur les pilotes. Un lien a été établi entre les périodes d'intérêt (PI), définies comme les périodes de fléchissement des scores MT et d'accroissement de l'activité cérébrale (EEG), et la perturbation des périodes circadiennes, lorsque les pilotes n'avaient pas eu le temps de s'adapter au décalage horaire. Les données portent également à penser qu'il faut tenir compte des effets de l'adaptation circadienne lors de l'établissement des cycles de travail des équipages et des heures de départ et d'arrivée des vols, dans les cas où les itinéraires comportent un décalage horaire.

Au terme de cette phase de l'étude, les chercheurs ont formulé les recommandations suivantes : (1) à partir des résultats aux tests multitâches, élaborer pour chaque pilote un indice personnalisé dont il pourra se servir pour évaluer objectivement son degré de fatigue; et (2) mettre au point une «routine» multitâches pouvant servir d'outil d'auto-contrôle de la fatigue et de contre-mesure à la fatigue pendant les vols.

17. Mots clés

Fatigue des pilotes, mesure de la fatigue,
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EXECUTIVE SUMMARY

The aim of this project was to develop methods for providing pilots with a personalized index of their fatigue to allow them to monitor the state of their own readiness during flight. The study was conceived in three phases, two of which have now been completed. Phase 1 was to develop the initial procedures for measuring brain function and information processing during flight. Phase 2 was to utilize those measures in procedures that were intended to initially assess the effect of long-haul flights on those measures and the implication of these observations for sleep-duty cycles. Phase 3 was conceived as the development of individual pilot fatigue profiles, as part of an individual index, and the testing of individual fatigue countermeasures based on the indexes.

Phase 1 of the study included a task analysis of the types of information processing required of pilots flying the Airbus 320 and Boeing 747 simulators. Electroencephalogram (EEG) instrumentation, using battery-powered amplifiers, and software were designed to allow the recording of gamma activity (40 Hz EEG) during flight. Initial data were recorded from pilots flying Airbus A320 in pairings that began at CFB Trenton, Canada and terminated in Zagreb, Croatia. These data were recorded in the extremely variable and difficult conditions characteristic of military flights into Zagreb. In addition, a laboratory study of gamma activity and multitasking (MT) during and after sleep deprivation was implemented in order to help interpret the data recorded in the air. The conclusions of Phase 1 were that multitasking and gamma activity interacted as a result of fatigue and stress. The gamma data recorded during fatigue was consistent with the interpretation that previously automated behaviour became less automated and required ‘re-binding’ as the result of fatigue. The results also suggested that during periods of high gamma activity, performance is maintained through increased effort (binding).

Phase 2 involved the collection of data from 10 Canada 3000 pilots flying between Vancouver or Toronto and Europe or Southeast Asia. A typical pairing to Europe would begin in Vancouver in the late afternoon (1700 to 1800 hours) and terminate in the early afternoon European time. Flights generally stopped in Calgary to pick up passengers and continued outbound. For pairings in which a long positioning flight was required after landing in Europe, crews sometimes laid over in Calgary and continued on the next evening. Flying time for the outbound trip was approximately 8.5 to 9 hours (Calgary to Europe). After a typical layover of 16 to 18 hours, the return leg to Vancouver usually began about 1300 hours local time (the time difference was 8 hours to the UK and 9 to continental Europe, so this would vary between 0400 and 0500 hours Pacific Time), landing in Vancouver during the afternoon. Flying time for the return trip was approximately 9 to 10 hours (westbound flights were somewhat longer). The South Pacific pairings were more variable. Pilots would usually layover in Honolulu (HNL) for between 24 and 48 hours. The second leg was a night flight to either Rarotonga/Auckland or Brisbane/Sydney. Often, a flight from Australia to New Zealand was made prior to returning to HNL, followed by a one-night layover, and then a return to Vancouver. Gamma activity was recorded during MT for 20-minute periods approximately every

three hours after take-off and preceding landing. Individual indexes of pilots were computed by combining EEG and MT results. Take-off and landing patterns were plotted relative to circadian periods.

The data suggested that there are important individual differences in the effect of jet lag on pilots. Periods of concern (PC) were defined as those periods when MT scores were declining and 40 Hz was increasing. Generally, the data suggested that PCs were related to problematic circadian periods, relative to Vancouver time, when there has been insufficient time for adjustment after jet lag. The data also suggested it is important that future consideration be given to the effects of circadian adjustments in the design of crew duty schedules and of departure and arrival times for pairings that include jet lag.

The use of EEG in the flight deck is difficult for pilots, and their level of cooperation in this study was remarkable, given the circumstances. Additional work needs to be done in the design of an MT test that can be easily used on the flight deck to give pilots on-line feedback about their state of preparedness to process complex information.

Recommendations of this phase of the study were: (1) to develop an individual multitasking index for each pilot through systematic collection of data during all flights so that periodic feedback of each pilot’s performance relative to that index can be used by that pilot to make an objective assessment of his or her fatigue; and (2) to develop a multitasking procedure that can be used as an index of fatigue, independently of EEG and as a countermeasure for fatigue during flights.

SOMMAIRE

Ce projet visait à mettre au point des techniques pour fournir aux pilotes un indice personnalisé de leur degré de fatigue, à des fins d’auto-contrôle pendant le vol. Les deux premières phases de l’étude sont achevées. La phase 1 a consisté à mettre au point des techniques permettant de mesurer l’activité cérébrale et d’évaluer la capacité de traitement de l’information des pilotes en vol. Au cours de la phase 2, ces techniques ont été utilisés pour étudier l’effet des vols long-courrier sur ces deux mesures, et les répercussions de ces observations sur les cycles de travail et de repos. La troisième et dernière phase doit comporter l’établissement de profils de la fatigue des pilotes, qui seront intégrés à un indice personnalisé, et l’évaluation de contre-mesures personnalisées à la fatigue, fondées sur ces indices.

La phase 1 comportait une analyse des tâches des pilotes aux commandes de simulateurs d’Airbus 320 et de Boeing 747, en vue de déterminer les types de traitement de l’information exigés d’eux. Des appareils EEG utilisant des amplificateurs à piles et un logiciel ont été expressément conçus pour permettre l’enregistrement par EEG de l’activité gamma (oscillations de 40 Hz) en vol. Les données initiales ont été recueillies auprès de pilotes qui volaient un Airbus A320 sur des itinéraires ayant comme point de départ la BFC Trenton, au Canada, et comme destination Zagreb, en Croatie. Ces données étaient enregistrées dans les conditions extrêmement variables et difficiles qui caractérisent les vols militaires à destination de Zagreb. Une étude en laboratoire de l’activité gamma et du rendement à des tests multitâches (MT), durant et après une privation de sommeil, a servi de point de comparaison pour l’interprétation des données colligées en vol. En conclusion de cette phase, les chercheurs ont noté une interaction entre les résultats aux tests multitâches et le degré d’activité gamma, interaction attribuée à la fatigue et au stress. Ainsi, l’activité gamma du pilote augmente lorsqu’il est fatigué, parce que, selon l’interprétation des chercheurs, les comportements qui étaient devenus automatiques le sont moins, sous l’effet de la fatigue, et qu’il doit, en conséquence, effectuer un nouveau liage. Les résultats donnent également à penser que, pendant les périodes d’activité gamma intense, le pilote déploie des efforts accrus (liage) pour maintenir son niveau de rendement.

La phase 2 comportait la collecte de données auprès de 10 pilotes de Canada 3000 effectuant des vols entre Vancouver ou Toronto et l’Europe ou l’Asie du Sud-Est. Un itinéraire type ayant pour destination l’Europe commençait à Vancouver, en fin d’après-midi (17 h à 18 h) pour se terminer en début d’après-midi, heure d’Europe. L’avion faisait habituellement escale à Calgary pour prendre des passagers avant de continuer sa route vers l’Europe. Dans le cas des itinéraires comportant un long vol de mise en place après l’atterrissage en Europe, les équipages avaient parfois une période de repos à Calgary, et poursuivaient leur route le lendemain soir. Le vol durait environ 8,5 à 9 heures (de Calgary à l’Europe). Après une période de repos type de 16 à 18 heures, ils repartaient habituellement vers 13 h, heure locale, vers Vancouver (comme le décalage horaire était de 8 heures avec le R.-U. et de 9 heures avec l’Europe continentale, il était entre 4 h et 5 h, heure du Pacifique), où ils atterrissaient dans l’après-midi. La durée du vol de retour

était d’à peu près 9 à 10 heures (les vols vers l’ouest sont un peu plus longs). Les itinéraires du Pacifique Sud étaient plus variables. Les pilotes avaient habituellement une période de repos de 24 à 48 heures à Honolulu (HNL). Le deuxième segment de leur itinéraire était un vol de nuit vers Rarotonga/Auckland ou Brisbane/Sydney. Souvent, ils effectuaient un vol de l’Australie à la Nouvelle-Zélande avant de revenir à HNL pour y prendre une nuit de repos avant leur vol de retour vers Vancouver. L’activité gamma était enregistrée durant les tests MT, soit pendant des périodes de 20 minutes qui revenaient environ toutes les trois heures au cours de la période de vol suivant le décollage et précédant l’atterrissage. Pour établir les indices personnalisés des pilotes, on conjuguait les mesures EEG et les résultats aux tests MT. Les chercheurs ont tracé des courbes des heures de décollage et d’atterrissage en fonction des périodes circadiennes.

Les données recueillies révèlent d’importantes différences individuelles en ce qui a trait aux effets du décalage horaire sur les pilotes. Les périodes d’intérêt (PI) ont été définies comme les périodes de fléchissement des scores MT et d’accroissement de l’activité cérébrale (EEG). De façon générale, les données indiquent un lien entre les PI et des périodes circadiennes perturbées, par rapport à l’heure de Vancouver, lorsque les pilotes n’avaient pas eu assez de temps pour s’adapter au décalage horaire. Les données portent également à penser qu’il faut tenir compte des effets de l’adaptation circadienne lors de l’établissement des cycles de travail des équipages et des heures de départ et d’arrivée des vols, dans les cas où les itinéraires de vol comportent un décalage horaire.

Même s’il n’est pas facile d’utiliser un appareil EEG dans un poste de pilotage, les pilotes ont collaboré de façon remarquable à l’étude. D’autres travaux sont nécessaires pour élaborer un test MT facile à utiliser dans le poste de pilotage, dont les pilotes pourraient se servir pour connaître immédiatement leur capacité de traiter de l’information complexe.

Au terme de cette phase de l’étude, les chercheurs ont formulé les recommandations suivantes : (1) établir pour chaque pilote un indice personnalisé de rendement aux tests multitâches, en colligeant systématiquement ses résultats au cours de chaque vol, de façon qu’il puisse, à l’aide des résultats, évaluer objectivement son degré de fatigue; et (2) mettre au point une «routine» multitâches pouvant servir à déterminer, indépendamment de l’EEG, le degré de fatigue, et constituer ainsi une contre-mesure à la fatigue pendant les vols.

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GLOSSARY

40 Hz	Oscillating electrical potentials recorded from the brain
A/D	Analogue to digital conversion
A320	Airbus A320 aircraft
AKL	Auckland, New Zealand, International Airport
AMS	Amsterdam, Netherlands, Schiphol Airport
BER	Berlin, Germany, Schoenefeld Airport
BNE	Brisbane, QLD, Australia, International Airport
CFB	Canadian Forces Base, Trenton, Ontario, Canada, Airport
Cz	Central midline electrode position
Delta	EEG activity in the range of ¼ to 4 Hz
EcoG	Electrocorticographic
EEG	Electroencephalogram
ERD	Event-related desynchronization
ERS	Event-related synchronization
FO	First Officer
Gamma	EEG oscillating activity in the range of 35 to 45 Hz
GLA	Glasgow, Scotland, UK, Airport
HAM	Hamburg, Germany, Fuhlsbuttel Airport
HNL	Honolulu, Oahu, Hawaii, USA, International Airport
LGW	London, England, UK, Gatwick Airport
MT	Multitasking
MUC	Munich, Germany, Franz Joseph Strauss Airport
NAN	Nadi, Fiji, International Airport
OGG	Kahului, Maui, Hawaii, USA, Airport
PC	Period of concern
Pz	Parietal midline electrode position
RAR	Rarotonga, Cook Islands, Airport
REM	Rapid eye movement
SYD	Sydney, NSW, Australia, Municipal Airport
UK	United Kingdom
V4	Inferior right hemisphere visual cortex
YMX	Montreal, Quebec, Canada, Mirabel Airport
YVR	Vancouver, British Columbia, Canada, International Airport
YYC	Calgary, Alberta, Canada, International Airport
YYZ	Toronto, Ontario, Canada, Pearson International Airport
ZRH	Zurich, Switzerland, Airport

1 INTRODUCTION

1.1 The Concept of This Study

The development of this study began in 1997 when the Transportation Development Centre, the Transportation Safety Board, and the Defence and Civil Institute for Environmental Medicine began discussions of the viability of measuring the impact of fatigue on information processing during long-haul flights. The idea was not only to assess subjective reports of fatigue but rather to look at the interaction of measures of brain function and information processing recorded from pilots during flight.

The study was conceived in three phases. Phase 1 was to develop the initial procedures for measuring brain function and information processing during flight. Phase 2 was to utilize those measures in procedures that were intended to initially assess the effect of long-haul flights on those measures and the implication of these observations for sleep-duty cycles. Phase 3 was conceived as the development of countermeasures based on the data of Phases 1 and 2. The data and conclusions of this report are those of Phase 2.

An important question in the development and implementation of Phases 1, 2 and 3 was whether methodologies could be developed that focused on the individual variability of pilots with respect to the impact of fatigue on performance. It is well known that there is a great deal of variability between individuals with respect to the effect of fatigue on performance. The question arose as to whether it would be possible to develop an on-line index for each pilot, in flight, of the times difficulties were encountered in information processing during long-haul flights. In addition, Phase 2 was intended to suggest scheduling constraints based on the broad effect of changes in day-night cycles during long-haul flights (jet lag) and possible impairments of performance with respect to layovers, departure times and landing times.

1.2 History of Phase 1 and Phase 2

This study is Phase 2 of a study to develop a method for assessing the capability of pilots to process information during long-haul flights that require adjustments to jet lag.

One of the goals of the study was to establish duty schedules that take into account individual variability of the effects of fatigue on performance and give to pilots a personalized index of their fatigue to allow them to monitor the state of their own readiness to process complex information, especially during emergencies.

Phase 1 of the study included a task analysis of the types of information processing required of pilots flying the Airbus 320 and Boeing 747 simulators. Instrumentation using battery-powered amplifiers was designed as well as the software necessary to allow the recording of gamma electroencephalogram (EEG) activity (40 Hz) during flight. Initial data were recorded from pilots flying Airbus A320 in pairings that began at CFB Trenton, Canada and terminated in Zagreb, Crotia. These data were recorded in the extremely variable and difficult conditions characteristic of military flights into Zagreb. In addition, a laboratory study of gamma activity and multitasking during and after sleep deprivation was implemented to help interpret the data recorded in the air. The conclusions of Phase 1 were that multitasking and gamma activity interacted as a result of fatigue and stress. Increases in gamma activity during fatigue, when performance is required, was consistent with the interpretation that previously automated behaviour became less automated and required ‘re-binding’, i.e., more control over processing and output and the re-establishment of automation. The results also suggested that during periods of high gamma activity, performance may be maintained through increased effort (binding); however, increased effort can fail to maintain performance under conditions of high stress or fatigue and performance can deteriorate (Weinberg, 1994a, 1994b, 1995).

Phase 2 of the study, the basis of this report, was intended to substantiate and explore further the implications of Phase 1, and to suggest flight-duty schedules that could reduce the effects of fatigue. Phase 3 was to develop the appropriate individual countermeasures that may be useful in reducing the effects of fatigue during duty.

1.3 The Concept of Sleep

We spend approximately one third of our life in the state of sleep. Volition (the will and choice to respond to the environment) and consciousness are partially or completely deferred, sensitivity to external stimuli is reduced, and physiological functions are partially suspended. What is the purpose of this behaviour that constitutes such a major portion of our existence yet provides us with such little conscious gratification?

Two primary types of theories have been proposed to answer this question: recuperation theories and circadian theories. The foundation of the recuperation theories argues that the homeostasis or internal stability of the body is disturbed by the waking state and sleep is needed to restore normal function. The circadian theories argue that animals sleep during the time of day when it is unnecessary for them to be engaged in survival behaviours. Wakefulness is necessary only to allow the animal to engage in behaviours that will satisfy basic needs. In this context, sleep conserves energy for the behaviours that are necessary for survival.

Prior to the 1950s the general concept of sleep was that the brain lapsed into sleep when sensory stimulation was insufficient to maintain wakefulness, and consequently alertness. Because sleep was thought of as a lapse in the waking state, the main problem for neurophysiology was to specify those neurophysiological systems that maintain an active, alert state. Sleep is now recognized as an active process characterized by a cyclic succession of different neurophysiological states.

Sleep is but one of the circadian rhythms that affect life. Indeed, all behavioural, psychological, and physiological processes are affected in some way by circadian rhythms. Each rhythm is affected by the light-dark cycle of the environment in which we live. When exposed to alternating periods of 10 hours of light and 10 hours of darkness, the circadian rhythm will shift to accommodate the new 20-hour day. When no light dark-cycles are present, the so-called ‘free-running rhythms’ that develop will vary for each individual, although a typical cycle will be greater than 24 hours and closer to 25. These free-running rhythms reflect the natural activity of an internal biological clock, free of external cues. When traveling between time zones, which differ in light-dark cues, body function is adversely affected. This phenomenon, called jet lag, illustrates the uneasy adjustment made by the internal biological clock in response to changing external cues of light and dark.

There is significant variation across species in the time each spends sleeping. Humans typically need 8 hours of sleep; the giant sloth needs 20 hours of sleep, and the horse only 2 hours. These differences provide a backdrop for contrasting the two types of major theories. For example, recuperation theories would predict that animals that expend more energy would need more sleep. There is, however, no correlation between the activity level of a species and the amount of time spent in sleep. Conversely, there is a correspondence between the level of vulnerability of a species during sleep and the amount necessary. Vulnerable animals such as zebras spend little time in sleep compared with the amount of time their predators (lions, tigers) spend in sleep. Hence, there is greater support for the circadian theories. This stronger support, however, does not eliminate the importance of the recuperative aspects of sleep. Indeed, an integration of the two purposes likely provides the most complete explanation for all the data.

Each type of sleep theory predicts a different outcome in the aftermath of sleep deprivation. The recuperative theories predict that the longer an animal is deprived of sleep, the greater the physiological and behavioural disturbance. The circadian theories predict no debilitating effects following sleep deprivation, a greater tendency to want to sleep during the usual time of day for this behaviour, and little or no compensation of sleep loss when sleep is again possible. The research supports both sets of predictions. Although long bouts of deprivation do not substantially increase compensatory sleep time, the brain does compensate for sleep loss by increasing the proportion of time spent in the presumably more restorative stages of slow-wave sleep. Rapid Eye Movement (REM) sleep is also an important behaviour. When subjects are repeatedly interrupted while in REM sleep, leading to deprivation, they show a rebound phenomenon. That is, when subjects are allowed to return to a natural sleep cycle, they spend a greater percentage of time in REM sleep than is normally the case.

Many different hypotheses have been offered to explain the purpose of sleep (particularly REM sleep). Among them are the vigilance hypothesis, the learning or memory consolidation hypothesis, the species-typical reprogramming hypothesis, and the brain development hypothesis. The vigilance hypothesis suggests that REM sleep provides a period of time when the animal is more aware of external stimuli and therefore provides a periodic opportunity to monitor for the presence of predators. The learning or memory consolidation hypothesis suggests that during REM sleep the brain is allowed to process the events of the day, integrating these with pre-existing memories. The species-typical reprogramming hypothesis speculates that REM sleep allows the brain to integrate what was learned during the day with the circuits that control instinctual behaviours. Finally, since human infants spend the majority of their sleep time in REM sleep, it has been speculated that this is associated with the extensive process of brain development.

Human sleep deprivation studies suggest that the brain, not the rest of the body, needs slow-wave sleep to recover from the day’s events. In support of this conclusion, quadriplegics (who are unable to be physically active) show only a small decrement of time spent in slow-wave sleep compared to physically active people. In addition, experiments that have increased the metabolic activity of specific brain regions have shown an increase in slow-wave delta activity in the same brain region the night following the manipulation.

Selective deprivation of REM sleep results in a REM rebound. By arousing subjects as they pass into REM sleep, REM sleep time can be drastically reduced by impairing slow-wave sleep. Curtailing REM sleep for several nights results in a marked increase in the duration and frequency of REM periods. The longer the deprivation period, the larger and longer the REM rebound. REM sleep declines during childhood and adolescence, levels off during the middle years, and then declines further with old age.

The brainstem has been implicated in arousal mechanisms that may be related to REM. There are two distinct arousal mechanisms situated in the brainstem: a dopaminergic system and a noradrenergic system. The relative activation of these systems is responsible for changes in arousal, normally regulated by circadian rhythms (see Section 1.6).

1.4 The Concept of Sleep-Related Fatigue

The concept of fatigue, like the concepts of learning, motivation, and stress, is a construct defined by measures or conditions antecedent to measures of performance or changes in physiology. The antecedent conditions are usually identified as sleep loss. Sleep loss may also lead to sleep debt, which is also frequently identified as an antecedent condition of fatigue in pilots (Airbus Industries, 1995). However, sleep loss is relative to the amount of sleep observed to be normally characteristic of an individual and sleep debt assumes there is a known amount of sleep usually required for the individual. The question of course is how to determine what is normally required for an individual. Furthermore, fatigue has many dimensions, not the least of which is fatigue resulting from physical exertion and sustained attention, and these interact with the effects of sleep deprivation and sleep debt. In addition, numerous other variables like chronic and situational anxiety, physical health, and some hormonal levels may have an impact on the length and characteristics of sleep. Age also contributes significantly to sleep-related fatigue. Increasing age results in less sleep during the night and increased sleepiness during the day (Davis-Sharts, 1989). For many years, degradation of performance has been used in many studies as an indicator of fatigue (Angus and Helsgrave, 1985). These and many other studies have identified the impairment of sensory or perceptual functions as well as the slowing, timing and disorganization of motor performance. It has been known for many years that fatigue occurs more frequently between 0000 and 0600 hours (Lyman and Orlady, 1981).

When sleep occurs in the context of fatigue, there can be a sudden and very rapid transition between the awake-state and the sleep-state. One moment the person is awake, conscious, and responding to external signals, and the next moment the person is unconscious and unable to respond. Preceding the transition to sleep, sometimes called the period of ‘fatal fatigue’, there is significant impairment of the person’s ability to respond to signals and process information – memory is impaired, reaction times are prolonged, and coordinated behaviour, attention and sensory processes like visual acuity are impaired. The period of fatal fatigue may increase gradually in severity until the sudden transition to sleep occurs.

Until what is known as ‘sleepiness’ occurs, i.e., the subjective feeling of fatigue-related sleep, the fatigued person may be the worst judge of his or her own state of sleep-related fatigue (Sasaki et al., 1986; Richardson et al., 1982; Rosekind et al., 1994; Dement et al., 1986). Without realizing it, the person may take greater risks in an effort to avoid increased effort, especially in monitoring tasks of the kind required of pilots (e.g., Barth and Holding, 1976; Hamilton et al., 1972). Periods of fatal fatigue can be exacerbated by movement restriction, impaired air circulation, sustained monitoring, and the demands of continuous vigilance that are characteristic of the automated flight deck (Colquhoun, 1976; Lille et al., 1979).

1.5 Pilot Fatigue

There is also a great deal of variability with respect to the ways in which pilot fatigue is defined. As suggested above, fatigue is distinguished from alertness and the need for sleep; indeed, fatigue may be present during states of high arousal and alertness. The relationship of fatigue to work in the transportation industry has been the source of a great deal of research. For example, Bougrin et al. (1995) characterized fatigue as “a set of manifestations generated by intense and prolonged work extending beyond a certain limit”. In the final analysis, fatigue should be considered in respect to the person’s total lifestyle, a point emphasized by Cameron as early as 1973.

There are several types of fatigue characteristic of aircrew workload that interact: fatigue of the sensory systems (e.g., visual and auditory fatigue), muscular fatigue, and what has been called mental fatigue (i.e., fatigue related to the processing of information). For example symptoms of visual fatigue include loss of acuity and focus, heavy eyes, and ocular burning sensations.

The history of fatigue-related incidents in flight is extensive and dates back as early as the reports of Charles Lindberg, who fell asleep, resulting in a near disaster during his famous New York-to-Paris flight in 1927. In 1943 Bartlet conducted one of the first systematic studies of the effect of pilot fatigue on pilot skills and information processing. In this study, alertness progressively deteriorated as well as a variety of behavioural measures, including timing and detection of course headings, speed and many others characteristic of flight deck operation. Behavioural measures became more variable and the timing of integrated actions resulted in the disintegration of separate components of the integrated processing, as if previous binding of information had become undone.

Back-of-the clock flying (flying during the hours normally devoted to sleep) is considered by most pilots to be more fatiguing than flight operations during daylight and early evening (Lyman and Orlady, 1981). The direction of flight has also been reported to be a factor. Eastward flights shorten the day and require a phase advance of circadian rhythms. Westward flights lengthen the day and require a phase delay. For example, decreased performance due to fatigue is expected during the afternoon and evening hours after a westbound flight, and during the morning and early afternoon after an eastbound flight. These effects are usually dissipated with two- to three-day layovers, depending on individual differences, after crossing more than six time zones.

The type of fatigue with which this report is concerned is fatigue of those brain functions that contribute to the processing of complex information, or brain function fatigue. Although brain function fatigue is a hypothetical construct, there are defined conditions that have neurophysiological consequences that are clearly related to impairments in performance and related information processing. For pilots these include: time on the task; time since awakening at the beginning the duty period; acute and chronic sleep debt; and circadian disruption resulting from jet lag. An extensive literature has developed in which fatigue has been related to a very large number of behavioural manifestations, including increased anxiety, decreased short-term memory, slowed reaction times, decreased work efficiencies, reduced motivational drives, decreased vigilance, increased variability in work related performance, and increased errors of omission and commission (Dinges, 1995).

In a study by Paul et al. (1998), 10 routine re-supply missions from Trenton to Zagreb were studied and involved 53 aircrew subjects. The crew wore wrist Actigraphs from approximately five days prior to the mission until the mission was completed. A battery of psychomotor tasks, including the multitask used in this study and described in Section 1.9, were completed by pilots during both outbound and return flights. On each mission the worst night of sleep occurred during the second night, in the UK, and was attributed to the effects of circadian shifts. Subjective ratings of alertness and fatigue became progressively worse during both transatlantic legs. The psychomotor tests and multitask data showed unequivocal fatigue-related lapses in performance on both transatlantic legs. Thirteen of the eighteen pilots tested showed performance ranging from minimal to marked impairments.

1.6 Circadian Rhythms

There are a variety of time-dependent changes in physiological systems ranging from the cellular systems in the brain to the physiological organization of the whole person. Circadian rhythms, identified in the 1970s, are rhythms related to a so-called biological clock that regulates the timing of biological and presumably some behavioural systems according to an approximate 24-hour cycle controlled primarily by brain-stem nuclei, the suprachiasmic nuclei of the hypothalamus. The activity of the suprachiasmic nucleus is itself influenced by the day-night cycle by means of fibres of the optic nerve originating in both retina and geniculate nuclei that are responsive to changes in light levels and to so-called entrainment processes after shifts in the light-dark cycle (Campbell and Murphy, 1998). Destruction of the suprachiasmic nucleus results in severe disruptions of the circadian clock. Increased activity of the suprachiasmic nucleus occurs during the light phase of the cycle. This circadian system probably acts to entrain and synchronize many biological rhythms of enzymes and neurotransmitters to optimize function of the total physiological system. Normally, circadian modes pass through a maximum and minimum period during a 24-hour period. Capabilities for complex information processing and motor behaviour are related to phases of the circadian rhythms.

There is individual variability with respect to the way circadian rhythms interact with performance. Generally, the patterns of effects of circadian rhythms on performance are maintained for high levels of performance. However, there are differences between individuals with respect to the effect of the day-night cycle on performance. Some individuals are ‘morning types’, whose performance is relatively better (with respect to the normal population) during light periods, and others are ‘evening types’, whose performance is relatively better in the evening. Furthermore, sleep loss produces an overall reduction in performance levels in both light and dark periods of the day. Increased motivation for performance generally elevates performance, especially during dark periods when performance would normally be low (Figires 1a, 1b).

Figure 1 Normal Individual Variability in Performance Related to Circadian Rhythms

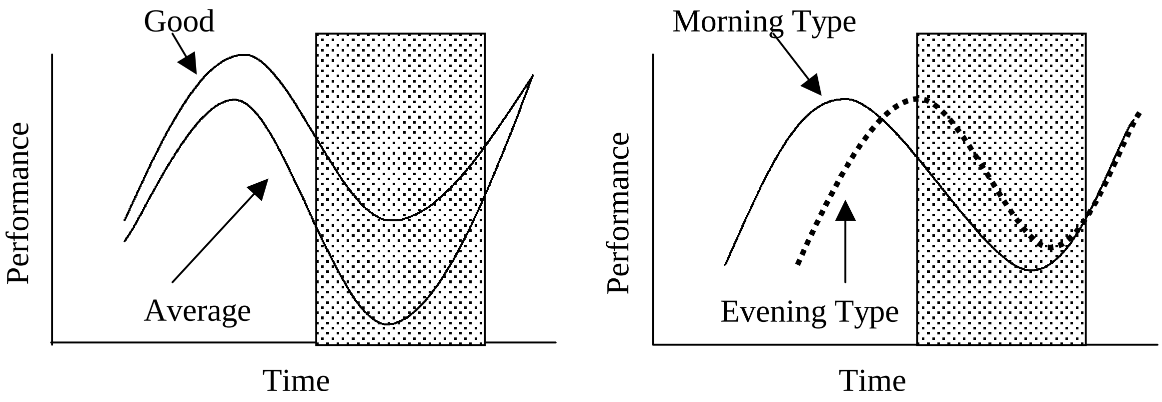


Figure 1a

Figure 1b

These circadian patterns occur in several homeostatic modes, including body temperature, systolic blood pressure, and cortico-hormone availability. Temperature is lowest during periods of inactivity and activity can raise temperature levels, but despite these factors, temperature levels also follow a definite circadian rhythm. In the late afternoon, body temperature can be as much as two degrees Fahrenheit higher than in the morning, and it will rise and fall even if light levels remain low.

Almost all hormones are regulated to some extent by circadian rhythms. Cortisol affects many body functions, including metabolism and regulation of the immune system. Its levels are highest between 0600 and 0800 hours, and gradually decline throughout the day. If changes in the daily sleeping schedule occur, the peak of the Cortisol cycle changes accordingly. Growth hormones stimulate growth in children and help maintain muscle and connective tissue in adults. Sleep triggers hormone production, regardless of when sleep occurs, and production peaks during the first two hours of sleep. During sleep deprivation, production of Cortisol drops. More strokes and heart attacks occur in the morning than at any other time of day. Blood pressure rises in the morning and stays elevated until late afternoon and then it drops off and reaches its lowest point during the night. These changes normally occur independently of physical activity. Brain stem neurotransmitters, e.g., the Gamma Amino Buteric Aergic of the brain stem system, play a critical role in the control of the activity of neurons in the control of sleep and waking states.

There are a great many studies showing performance and other behavioural decrements during shift work when circadian systems produce pressures to sleep during work and pressures to remain awake during periods when sleep is required. These studies are also evidence for the effect of cumulative sleep debt (Perelli, 1980; Monk, 1990).

In the context of aviation, studies have found that overnight cargo pilots accumulated significant sleep debt (Gander et al., 1989) and pilots who had been awake for more than 15 hours accumulated significant sleep debts of eight to nine hours after flying two night flights, outbound and return. East-west flights had significantly longer layovers but were more disruptive to circadian rhythms (Samel et al., 1997). An amazing observation by Gander et al. (1993) was that 11 percent of pilots they studied fell asleep for an average of 46 minutes during night flights. Because of the time it takes for adjustments to circadian shifts, pilots often find it difficult to adjust during layovers. Aircrew reports of increased fatigue occur significantly more between 0000 and 0600 hours (Lyman and Orlady, 1981).

1.7 Electroencephalogram (EEG) and Sleep

The EEG of a human during wakefulness is predominately characterized by high-frequency, low-voltage brain wave activity (beta band, 13 to 24 cps). Increased beta wave activity is associated with alert problem solving and behaviour.

When one begins to fall asleep, the EEG begins to slow. Brain-wave activity in the alpha band is common. It is easy to be aroused by external stimuli. Stage 1 sleep follows this transition from wakefulness, and is of brief duration (5 to10 minutes). Stage 1 sleep is characterized by alpha (8 to12 cps) and emerging theta wave activity (4 to 7 cps). During this stage, breathing and heart rate decline along with muscle tone and temperature.

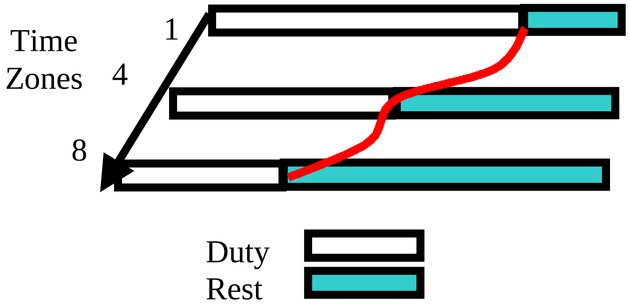
During Stage 2 sleep, breathing, heart rate, muscle tone, and temperature continue to decline. Brief bursts of high-frequency brain-wave activity are superimposed on an EEG of varying frequency. These bursts of high-frequency activity are called ‘sleep spindles’.

As one moves deeper into sleep, physiological as well as EEG activity slows further. The slow-wave sleep of Stage 3 and Stage 4 sleep is characterized by ever-increasing amounts of delta wave activity (less than 4 cps). One usually enters slow-wave sleep toward the end of the first hour of sleep and stays in that state for approximately 30 minutes.

After Stage 4 of the slow-wave period, the cycle reverses itself and slowly moves backward into lighter stages of sleep. This is when REM sleep, or Stage 5 sleep occurs. Rapid eye movements are prevalent during this stage of sleep. Irregular breathing and heart rate are also characteristic of REM sleep. EEG activity during this stage is similar to that found during wakefulness, dominated by low-amplitude (voltage), high-frequency beta waves. Most dreaming occurs during REM sleep. In a classic study, subjects who were awakened during REM sleep reported dreaming 78 percent of the time. When subjects were awakened during any of the other stages of sleep (Non-REM sleep, or NREM), they reported dreams only 14 percent of the time. Although the mind is very aroused and active during REM sleep, it is very difficult to awaken someone in this state.

During a night’s sleep, we cycle through the various stages approximately four times. The first REM period is brief (only a few minutes long), but each successive cycle results in a REM period of greater duration. Shortly before we awaken, the typical REM period will last approximately one hour. As the duration of REM sleep increases throughout the night, the duration of NREM sleep decreases. This means that most slow-wave sleep occurs early in the night cycle, and most dreaming occurs later. Young adults will typically spend approximately 60 percent of their sleep cycle in light sleep (Stages 1 and 2), 20 percent in slow-wave sleep (Stages 3 and 4), and the remaining 20 percent in REM sleep. Infants and young children sleep longer and spend a greater amount of time in REM sleep. With increasing age, the proportion of time spent in slow-wave sleep decreases, and there is a shift toward lighter sleeping. Cultural customs such as co-sleeping (parents and children sleeping together) or napping (siesta cultures) may affect sleep behaviours but do not affect the psychological or physiological experience of sleeping. However, increased EEG activity during sleep (e.g., dreaming) is usually associated with increased arousal. REM sleep, high frequencies in the range of beta activity, when occurring during sleep and usually accompanied by loss of muscle tone and lateral eye movement, is characteristic of dreaming. Sasaki et al. (1986) reported that REM sleep decreased and slow-wave sleep increased during the major off-duty sleeps of crew during trans-American operations.

Figure 2 Relationship of Duty Cycles to Jet Lag

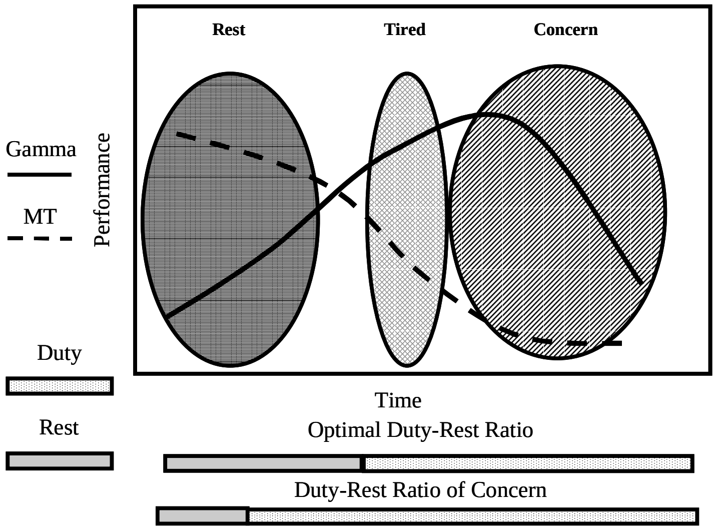


- Rest period requirements are a function of number of time zones
- Increased rest periods allows adjustments to changes in day-night cycles

1.8 Duty-Rest Cycles

There is a clear relationship between the times required for a circadian adjustment as the result of jet lag. Figure 2 is a diagrammatic representation of the relationship between recovery time and the number of time zones traversed for maximum performance. The line connecting duty cycles indexes inertia for recovery. Inertia for recovery is influenced by age and the duration of sleep preceding the test. Generally, inertia for recovery after jet lag becomes greater with the amount of sleep debt accumulated. Gamma activity results from feed forward and feedback systems in the brain both within the cortex and between cortex and subcortical structures.

Figure 3 Theoretical Relationship of Gamma to Performance and Duty Cycle



The relationship of gamma activity to the duty cycle is shown in Figure 3. Performance is best when gamma activity is low and multitasking performance is high because there is less effort required to achieve good performance. This occurs with an optimal duty-rest schedule, which in Figure 3 shows duty as approximately 1/4 the daily period. As the duty cycle changes to a greater proportion of the day attributable to duty, the amount of effort, indexed by the gamma activity, increases until an exhausted individual cannot maintain effort and information processing is impaired as the result of fatigue.

1.9 Multitasking

In recent years, there has been an increasing recognition that complex information processing always occurs in a context of multitasking.

Even when there is apparently only one task required, that task frequently requires simultaneous performance of other tasks and information processing that is not overtly recognized.

Normal executive activity, like those in the media, industry, road vehicle and rail operations, and other common activities all require multitasking. A common example is air traffic controllers, who must use selective attention in both auditory and visual modalities, and must continually adjust and coordinate auditory feedback and verbal instructions to pilots. In addition, they are required to continually scan the visual field for the unexpected and, depending on the circumstances, they may also be engaged in many other types of concurrent processing. Traditionally, these types of information processing can be studied separately in a laboratory; however, in a real working environment, they are all occurring and interacting simultaneously. Theories of information processing sometimes disagree as to whether information is actually processed in parallel or whether scanning occurs. However, the reality of processing in a normal environment is that multiple dimensions of information are almost always present and the subject must almost always use multiple sensory input and continuous feedback from motor output.

An extremely complex constellation of input may be required for a simple output; an extremely complex output, extending over a period of time, may be triggered by one element in a complex input. Furthermore, the more complex the input and output, the more variability is observed with respect to the ways in which individuals process information that is presented simultaneously, especially if elements of the information interact.

It is therefore important to develop procedures for the measurement of how individuals function in a multitasking context, particularly for those environments that incorporate critical types of information processing and performance. One of the most important factors influenced by fatigue is critical performance requiring multitasking during sustained operation, which depends on complex information processing. Critical performance means that the consequences of failure are catastrophic, as they may be in flight (Angus et al., 1981; Angus and Helsgrave, 1983, 1985; Pigeau et al., 1987). Multitasking can become automated or pre-programmed, with practice. Driving is a simple example of extremely complex pre-programmed output. It is said that all of the required discriminations and motor functions can operate without ‘thinking’. In some sports this automation is encouraged and ‘thinking about the output’ actually impairs the output.

Computers can also learn to multitask. Computer multitask learning is said to be an inductive transfer method that improves generalization by using domain information implicit in the training signals of related tasks. It does this by learning multiple tasks in parallel using a shared representation. Multitask transfer in connectionist nets has already been proven.

Automation that is characteristic of multitasking is vulnerable to a variety of factors that are both external and internal to the person. The external factors are those that deviate to a large extent from the information that was used to establish the automation. Internal factors are those that impair short-term and long-term memory, selective attention, scanning, and sensory processing. If a highly automated behaviour fails, it may fail completely since each element of the behaviour may depend on preceding outputs and feedback from concurrent or subsequent outputs. If part of the program fails, the whole program may collapse.

Applied Brain Behaviour Systems Ltd. has studied multitasking and concurrent brain processes in rail operators controlling engines, air traffic control environments, pilots on long-haul flights, and vehicle operations. Observations of brain function allow the design of multitasking requirements that best predict when the system will fail, especially in respect to individual variability.

Recent evidence suggests that feedback systems in the brain become stabilized and optimized during the development of automated behaviours in multitasking contexts. An index of the activity of these systems is the density of frequencies in the range of 35 to 45 Hz in the EEG of spontaneous activity during periods of information processing - called gamma activity.

1.10 Gamma Activity

Recently there have been many studies of high-frequency EEG activity in the range of 35 to 45 Hz. This gamma band activity exists in a number of brain structures of different species, with different functional and behavioural correlates. This rhythm has dynamics in various structures that are influenced by different kinds of information processing. Gamma activity exists spontaneously but can also be evoked or emitted with different latencies and relationships to sensory and cognitive events. Recent measurements of gamma band activity at both the macro and cellular levels have suggested functional relationships of gamma to cognition, such as the perceptual binding of previous memories and stimulus features. It has been shown that distributed gamma fields, measured in both humans and animals, may have multiple functions in what is termed ‘obligatory’ sensory and cognitive processing. With respect to the generators of gamma activity, experimental data hint at the existence of a widely distributed gamma system in the brain. Recent theories of intra-cerebral function suggest that these gamma band frequencies may be the result of ‘re-entrant processes’ in the brain (Edelman, 1989), reflecting the interaction between parts of highly complex and widely distributed systems in the brain. The analysis of gamma band activity, in conjunction with behavioural measures in multitasking environments, was successful in classifying the expertise of air traffic control experts (Weinberg, 1994a, 1994b), and has been used to study information processing in long-haul flights and, many other complex environments (Weinberg et al., 1989, 1991, 1999; Weinberg, 1999). It has recently been shown that efforts requiring increased and focused attention for the performance of discriminations, especially those that require selective attention (Kelso et al., 1998; Kobayayashi et al., 1998) result in an increase in gamma activity. Studies of parallel distributed networks in the brain suggest that gamma activity reflects the degree of 'binding' that is necessary for the processing of information (e.g., Basar-Eroglu et al., 1996). Binding refers to the linking of different elements of the information that must be processed. For example, it may be the linking between auditory and visual input and the linking of those inputs with memories that must be retrieved for discriminations, decisions, and actions, all within a complex environment.

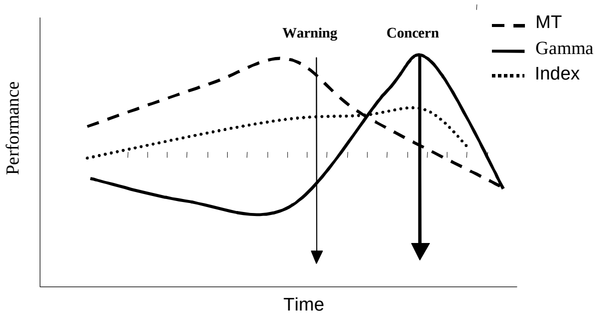


Figure 4 Theoretical Relationships of Index to Performance

It appears that gamma activity indexes the degree to which active binding of memories and input is required for performance. It would therefore be expected that performance, which is not automated, would be indexed by an increase in gamma activity. This is consistent with almost all of the research that has been reported. When cognitive processing becomes automated and results in well practised and easily accessed performance, gamma activity should decrease (Figure 4).

If, as the result of sleep deprivation and fatigue, normally automated cognitive behaviour and well practised automated performance require more active binding, more active searching through memory, and more planning of the response to input, it would be expected that gamma activity would increase**.** Carruthers et al. (1976) measured the slower frequencies of EEG on crew operating from Buenos Aires to London via Madrid and Paris. During the early morning hours (0400 to 0600) the pilots showed EEG patterns characteristic of sleep and drowsiness, including sleep spindles (bursts of 12 to 14 Hz) and increased synchronization of the EEG (a sign of sleep).

Recent reports in neuroscience describe how the brain 'binds' together separately coded stimulus features to form unitary representations of objects. Recent evidence has indicated a close link between this binding process and 40 Hz (gamma) oscillations generated by localized neural circuits. The ability of young infants to perceive objects as unitary and bound has become a focus for discussion about the mechanisms of perceptual development and its relationship to binding. Csibra et al. (2000) recently demonstrated that binding-related 40 Hz oscillations are evident in the infant brain around eight months of age, which is the same age at which behavioural and event-related potential evidence indicates the onset of perceptual binding of spatially separated static visual features.

The visual cortex of the primate brain manages to focus attention on one object while ignoring all of the other objects in the field of view. Stryker (2001) reviewed the data, which demonstrate that neurons in the V4 region of the visual cortex that are activated by the ‘attended’ stimulus show remarkable synchronization of their electrical discharges in the gamma frequency range (35 to 45 Hz), whereas neurons activated by distracting stimuli do not. Crone et al. (1998) noted that gamma activity evoked by sensory stimuli is functionally mapped in the sensory cortex.

It has been shown in animals that neuronal activity in the gamma band (>30 Hz) is associated with cortical activation and may play a role in multi-regional and multi-modal integration of cortical processing. Studies of gamma activity in human scalp EEG have typically focused on event-related synchronization (ERS) in the 40 Hz band. To assess the gamma band ERS as an index of cortical activation and as a tool for human functional brain mapping, subdural electrocorticographic (ECoG) signals were recorded in five clinical subjects while they performed visual-motor decision tasks designed to activate the representations of different body parts in the sensorimotor cortex. ECoG spectral analysis used a mixed-effects analysis of variance model in which within-trial temporal dependencies were accounted for. In an exploratory approach, gamma ERS was studied in 10-Hz-wide bands (overlapping by 5 Hz) ranging from 30 to 100 Hz, and findings were compared with changes in the alpha (8 to 13 Hz) and beta (15 to 25 Hz) bands. Gamma ERS occurred in two broad bands: low gamma included the 35 to 45 and 40 to 50 Hz bands, and high gamma the 75 to 85, 80 to 90, 85 to 95 and 90 to 100 Hz bands. The temporal and spatial characteristics of low and high gamma ERS were distinct, suggesting relatively independent neurophysiological mechanisms. Low gamma ERS often began after onset of the motor response and was sustained through much of it, in parallel with event-related desynchronization (ERD) in the alpha band. High gamma ERS often began during, or slightly before, the motor response and was transient, ending well before completion of the motor response. These temporal differences in low and high gamma suggest different functional associations with motor performance. Compared with alpha and beta ERD, the topographical patterns of low and high gamma ERS were more discrete and somatotopically specific, and only occurred over contralateral sensorimotor cortex during unilateral limb movements (alpha and beta ERD were also observed ipsilaterally). Maps of sensorimotor function inferred from gamma ERS were consistent with maps generated by cortical electrical stimulation for clinical purposes. In addition, different task conditions in one subject produced consistent differences in both motor response latencies and onset latency of gamma ERS, particularly high gamma ERS. Compared with alpha and beta ERD, the topography of gamma ERS is more consistent with traditional maps of sensorimotor functional anatomy. In addition, gamma ERS may provide complementary information about cortical neurophysiology that is useful for mapping brain function in humans.

2 METHODOLOGY

2.1 Testing in Flight

The data was collected from 10 Canada 3000 pilots flying between Vancouver or Toronto and Europe or Southeast Asia. A typical pairing to Europe would begin in Vancouver in the late afternoon (1700 to 1800 hours) and terminate in the early afternoon Euro time. Flights generally stopped in Calgary to pick up passengers and continued outbound. For pairings in which a long positioning flight was required after landing in Europe, crews sometimes laid over in Calgary and continued on the next evening. Flying time for the outbound trip was approximately 8.5 to 9 hours (Calgary to Europe). Pilots usually retired to a hotel after arrival for three or four hours of sleep, after which they had dinner at about 1800 hours local time and retired for additional sleep at about 2300 hours. After a typical layover of 16 to 18 hours, the return leg to Vancouver usually began about 1300 hours local time (the time difference was 8 hours to the UK and 9 to continental Europe, so this would vary between 0400 and 0500 hours Pacific Time), landing in Vancouver in the afternoon. Flying time for the return trip was approximately 9 to 10 hours (westbound flights were somewhat longer). The South Pacific pairings were more variable. Pilots would usually get to Honolulu (HNL) and stay for between 24 and 48 hours. The second leg was the night flight to either Rarotonga/Auckland (RAR/AKL) or Brisbane/Sydney (BNE/SYD). Often, a turn from Australia to New Zealand or vice versa was made prior to returning to HNL, followed by a one-night stay, and then a return to Vancouver.

Pilots were asked to undergo testing with the multitasking (MT) and EEG procedures at least twice during the outgoing trip and twice during the return leg of the trip. Because of differing exigencies in each flight, the testing times varied considerably. Pilots were informed that individual data would be coded and kept confidential.

Figure 5 EEG and Multasking in the Air

The multitasking and EEG devices were set up in the flight deck of the aircraft Captains were tested in their seats when the First Officers (FOs) assumed control of the aircraft and the FOs were tested when the Captains were in control (Figure 5).

After application of the electrodes and electrode cap, each testing session lasted 20 minutes, during which the pilots were tested on MT. Ten-second samples of spontaneous EEG were also recorded. The number of samples recorded varied, depending on what was happening in the cabin during the testing period.

2.2 Multitasking and EEG

Figure 6 Multitasking Display

The multitasking program was configured to run on a laptop computer. The program included four tasks that were presented simultaneously in four different quadrants of the screen as shown in Figure 6.

The tasks included a visual-motor tracking task, a display of waypoints over which the pilot had to ‘fly’, a display of two attitude indicators that sometimes differed, and a series of histograms, the length of which changed from time to time (Figure 6). Two of the tasks interacted directly in the sense that they were linked. The complex tasks were described in detail in written instructions given to the pilots before testing (see Appendix G).

The EEG recording device was designed and constructed specifically for this study. It consisted of a two-channel system powered entirely by four 9 V batteries. The pilot was completely isolated from any power source. The EEG amplifiers were contained within a small 10 x 10 x 10 cm aluminium box and connected by cable to an A/D card in a battery-powered laptop computer. Three electrodes were applied with a conductive paste that could be removed easily with water. The electrodes were disposable, silver-silver-chloride discs approximately 5 mm in diameter. The procedure for applying the electrodes was simply to deposit a small amount of paste on the subject’s scalp and press the electrode into the paste. The paste semi-hardened sufficiently to hold the electrode in place. Two electrodes were placed on the midline of the scalp at positions Cz and Pz, according to the 10/20 International EEG Protocol. One electrode was placed on the mastoid process as the reference. A ground electrode was placed on the forehead. Since all electrical components were powered by battery and completely isolated from any external electrical sources, no electrical earth was necessary. Electrodes were removed between recording sessions.

3 DATA ANALYSIS

3.1 Multitasking

The MT program was configured to give scores for:

1. Time off bearing, and time off altitude cross hairs
2. Detection of differences in matched attitude indicators with respect to
    - Average detection time and average decision time
    - Total hits
    - Correct hits
    - Incorrect hits
    - Misses
    - False alarms
3. Average time out of range for each of the five histograms
4. Waypoints
    - Number of waypoints reached
    - Time off waypoint heading
5. Altitude changes
    - Number of altitude changes
    - Average time off instructed altitude

The combination of these values produced a total error score.

3.2 EEG

For each trial, data were filtered between 35 and 45 Hz. The filtered data was then rectified and sorted. Averages of the 10 highest gamma values were computed. This comprised the individual gamma data for each recording session.

3.3 Data Index

A non-normalized index was computed for each recording session by subtracting the gamma value divided by 1000 from the MT score. Thus, as the gamma score became greater than the MT score, the values were negative. A normalized index was also constructed as the baseline for each pilot by taking the average of the indexes in the first two recordings during the pilots' first recorded pairing.

3.4 Multitasking and Gamma Data

The most pervasive observation was the variability between individual pilots with respect to the effect of jet lag. Graphical representations of the non-normalized and normalized indexes as computed are shown in Appendix E. This was an attempt to develop for each pilot an index of performance that combines the MT score and the 40 Hz observed values. The non-normalized graphs also show the value that corresponds to zero value for the normalized data.

Appendix A shows the overall MT score and gamma values for each time period in each pairing for each pilot. Oval markers on the plots are periods when the data suggest the pilots were having difficulty (called periods of concern, or PC). Difficulty is defined as those periods when MT was low in the context of increased effort as indexed by 40 Hz, or periods when MT and 40 Hz dropped concurrently to low values. This latter condition was construed as the situation in which the pilots were fatigued and could no longer maintain the effort needed to elevate the MT scores. Appendix B shows the average of Cz and Pz densities of 40 Hz without scaling and Appendix C the total raw MT score.

Pilots 1 and 5 are shown on the same graph in Appendix A because of the limited number of observations for these pilots. Pilot 1 shows PC in pairing 4960 at approximately 0000 hours Vancouver time, which suggests that there was no recovery from jet lag. This time would correspond to 1900 hours at departure for return to Vancouver. Thus, the data indicate that if there had been adjustment to the new circadian period, then departure was not relative to that adjusted circadian period. If there was no adjustment, the departure of 0000 hours Vancouver time would be in one of the worst circadian periods for performance. Pilot 5 shows a similar pattern for pairing 3198, which was Toronto based, in which PC is approximately at 0000 hours Vancouver time and 0300 hours Toronto time.

Pilot 2 shows PC in pairing 4303 at approximately 0900 hours Vancouver time – which corresponds to 0400 hours departure time – as the result of a layover of less than three days. In this case it would be expected that there had been no circadian adjustment to the departure location, and the observation occurring just before destination time was at a problematic circadian period, when it would be expected that pilots would be fatigued relative to their departure location. Pilot 2 also shows PC at approximately 0500 hours Vancouver time in pairing 4305, which corresponds to 1745 hours at departure after approximately two days' layover, which was apparently not sufficient for circadian adjustment. The data for pairing 4305 suggests the pilot was still functioning according to Vancouver time. In pairings 4312 and 4331, there are similar periods of PC when effort is elevated according to gamma observations in the context of falling MT scores. In pairing 4312 the observations were made at approximately 0230 hours Vancouver time, corresponding to 1030 hours departure time, indicating that circadian adjustment had not been made and the observations were made at a circadian period corresponding to reduced performance. This is similar for the observation made at approximately 0700 hours Vancouver time for pairing 4331. In general, the data for this pilot suggests there had been no adjustment to jet lag and the pilot was operating primarily on Vancouver time.

Pilot 4 shows PC in pairing 4316 when, as a result of a layover of less than three days, the pilot's circadian period had apparently not shifted. The period of PC is related to the time relative to 0600 hours Vancouver time in pairing 4306. The PC occurs at approximately 0530 hours Vancouver time and corresponds to a less than optimal period in the circadian period relative to Vancouver time, probably due to a layover of less than three days, resulting in function that was more related to Vancouver time than the destination time. In pairing 4300 at 1100 hours Vancouver time, corresponding to 2200 hours at departure location, and taken as the last observation before landing, the data indicate that the pilot is fatigued. The MT shows poor performance in the context of reduced effort, particularly in comparison with the previous observation, which showed increased effort to maintain performance. In this pairing, the layover was less than three days and the results may be due to an increasing sleep debt if the pilot had difficulty sleeping during the layover. For pairing 4314, the PC is at about 0100 hours Vancouver time, also suggesting fatigue due to an incomplete shift in the circadian period that resulted from a layover of less than three days. In general, the data would suggest that for this pilot, an increased layover time is necessary for jet lag of eight hours or more.

Pilot 6 also shows PC around 0500 hours Vancouver time, or 1300 hours at departure location, for pairing 4307. If the pilot had not shifted his circadian period, this time would be problematic and since the layover in this case was less than three days, the PC is probably related to an incomplete adjustment to the circadian period established in Vancouver. This PC is similar to that suggested in pairing 4312. Generally, these PCs are apparently related to the lack of sufficient time to adjust to local time.

Pilot 7 shows several PC periods in all pairings that are three-day trips. In pairing 4306, the PC is at approximately 1500 hours Vancouver time and at 2200 hours at layover location on the return trip just before landing. Although the circadian period is within the Vancouver period that would predict acceptable performance, the PC may have resulted from sleep debt due to the take-off time from the layover location, which was approximately 0000 hours Vancouver time. At that time an increased effort was required, as indexed by gamma activity, to maintain a good MT score. In pairing 4301, two periods appear to be problematic, one at about 1800 hours Vancouver time, corresponding to 0300 hours at layover location. In the second pairing of 4306, shown for Pilot 7, PCs are between 0200 and 0600 hours Vancouver time. In pairing 4303, PCs are also in the early morning corresponding to Vancouver time.

Pilot 9 shows PC at approximately 0600 hours Vancouver time in pairing 4332, corresponding to 1400 hours at layover location. At approximately 1830 hours Vancouver time this pilot shows increased gamma activity, presumably for the maintenance of the MT.

Pilot 10 is interesting in that pairing 4314 shows PC at approximately 2100 hours Vancouver time on the outbound trip; however, in pairing 4332, where there had been more than three days of layover, there is apparently no PC on outbound or return flights.

Appendix C shows the non-normalized results. There is considerable variability with respect to the scores. Generally, it can be seen that most pilots were able to achieve a raw score of 1000 or more (the hatched line on each graph). If 1000 is taken as the level that should be achieved, it can be seen that some pilots (1 and 5) do not often reach this criterion. This is probably because of the limited experience the pilots have had with the multitasking. However, the times shown as problematic in Appendix A, when multitasking is low and effort is high, generally correspond to the times when the pilots are scoring low on the MT with respect to the criterion MT score.

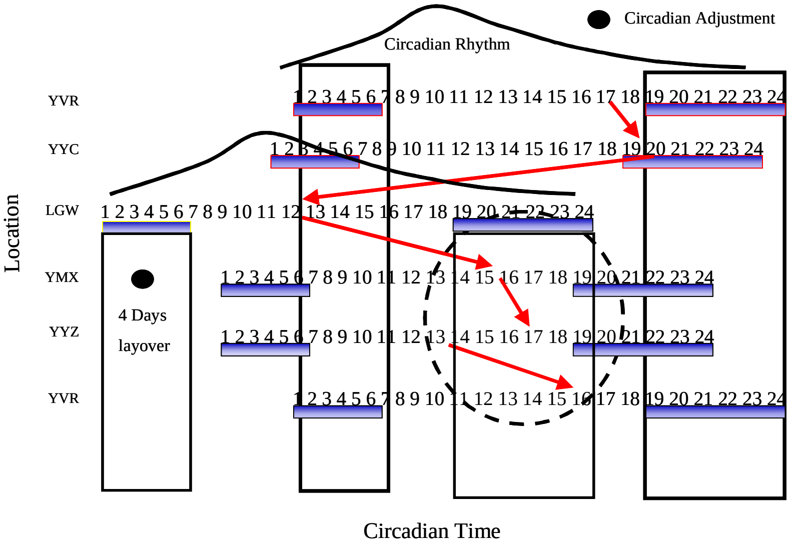
4 DISCUSSION AND CONCLUSIONS

Generally, the data suggest that PCs that are related to the problematic circadian periods relative to Vancouver time occur when there has been insufficient time for adjustment after jet lag. This is not surprising, since circadian adjustment usually takes three or more days for jet lag exceeding eight hours.

Long-distance flights with rapid time-zone shifts of more than three hours lead to a dissociation of the inner circadian clock from the outer pacer. Since the inner circadian rhythm tends to be 24 to 26 hours, travelling westward with a prolongation of daylight will be tolerated better than travelling eastward, which shortens the day. Rapid time-zone shifts of more than eight hours to the east lead to different ways of resynchronization. Subjects either try to adapt to the new time zone by shortening the day (backward adaptation) or they resynchronize forward with a longer duration of adaptation time. Older pilots who may have diminished circadian hormonal rhythm may have more problems in adapting to shifts in circadian periods. After flights to the west, within three to seven days most circadian rhythms will be resynchronized. After flights to the east, resynchronization may take five to fourteen days.

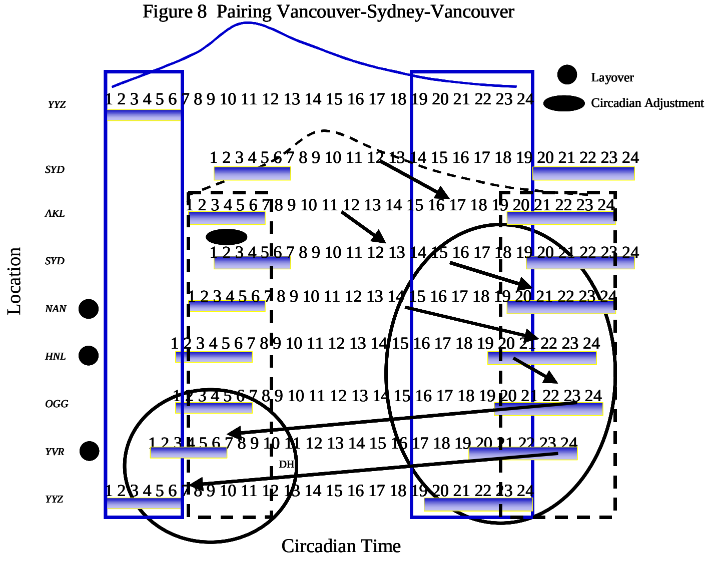
UK Civil Aviation Authority policy defines acclimatization (having adjusted to a shift in circadian periods) as occurring when a crew member has spent three consecutive local nights on the ground within a time zone that is two hours wide, and is able to experience uninterrupted sleep. The crew member is assumed to remain acclimatized thereafter until a duty period finishes in a place where local time differs by more than two hours from that at the point of departure.

Figure 7 Pairing Vancouver-London-Vancouver



In this study, take-off and landing times were examined relative to the local day-night cycle. For example, in the pairing shown in Figure 7, the pilots leave at approximately 1200 hours, a time period that is not optimal with respect to performance but is in daylight. The pilots reach the destination at 2000 hours according to the circadian period that was established before departure. In this pairing, the pilots leave during the night, without layover, and arrive in London (LGW) during the day but at a very difficult circadian period (approximately 0100 hours) relative to that circadian period established at home base before any adjustment could occur. The pilots then have a four-day layover in LGW, which readjusts their circadian period to correspond to the day-night cycle of LGW. Landing and take-off in completion of the pairing then occurs at night (relative to the new circadian period), in what would be very difficult periods that would be expected to be accompanied by fatigue.

Figure 8 Pairing Vancouver-Sydney-Vancouver



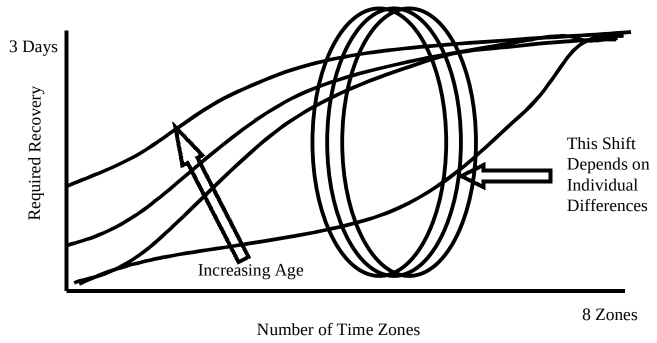
Another example of a very difficult paring is shown in Figure 8. In this pairing there has been an adjustment of the circadian period as the result of a layover in AKL, and landing and departure for all times relative to the circadian adjustment are in very problematic periods. Final destination upon return to Toronto (YYZ) after a layover in Vancouver (YVR) is not sufficient to reset the circadian clock.

Höne (1994) studied stress and fatigue during long-haul night flights using conventional methods of EEG and measures of subjective fatigue. He came to the conclusion that night flying is associated with significant sleep deficits and that, during layover, sleep loss could not be completely compensated for by the sleep period that actually took place during the daytime following arrival. The study showed that after returning to home base after night flights that included circadian shifts, at least 48 hours of rest, “if not more to be on the safe side,” are required for recovery. These results suggest that a minimum of 48 hours should be considered for readjustment to a circadian shift resulting from jet lag resulting from crossing eight or more time zones. This is particularly important because it is usually difficult to sleep during the daylight hours of the first 24 hours of recovery after the shift. These observations are consistent with those discussed by Samel and Wegmann (1989). Age is also a factor. As the individual gets older more time is required for adjustment to jet lag; however, there are considerable individual differences in this respect. A theoretical relationship showing the number of recovery days necessary for accommodation to jet lag as a function of age is shown in Figure 9.

If it is assumed that there has been no circadian adjustment for layovers of less than three days then, as Appendix B suggests, there are many departures and arrivals executed in the early morning or evening when the effects of fatigue would be expected to be significant.

Figure 9 Theoretical Recovery Days Relative to Jet Lag

Necessary for Optimal Performance as a Function of Age



In Appendix E, an attempt has been made to develop an index by combining the observations of MT with those of 40 Hz density. Two types of data were computed: an index that normalized the data on the first two observations of the first pairing for each pilot and an index that was related to the resting baseline when it was available. The non-normalized index and the raw data make it clear that the baseline data, collected in the home of each pilot during rest, are not the best indicator of MT and 40 Hz that would be expected to occur during flight under normal conditions without fatigue. The MT and 40 Hz in the home environment did not include the requirements of actually performing the tasks in the very different environment of the flight deck. For that reason, the normalization was made relative to the first two observations in the air. The normalized index depends to some extent on the factor used to scale the MT score. In developing the index, the MT score was divided by 1000 to bring it into the scale of the 40 Hz, and the index was the value resulting from the subtraction of the 40 Hz from the scaled MT so that negative values indicated a greater score of the 40 Hz relative to the MT. This was done to the index when there was increasing effort (a greater 40 Hz value) when the MT score was declining as an indication of fatigue. The normalized index simply used the index for the first two indices, from the first two data collections in the air, as the baseline. This approach is shown in Appendix E. Generally, the index shows negative values in the same time periods that are interpreted as problematic in Appendix A (raw data).

The data also suggest that there are important individual differences in the effect of jet lag on pilots. It is important that future consideration be given to the effects of circadian adjustments in the design of crew duty schedules and of departure and arrival times for pairings that include jet lag.

The use of EEG in the flight deck is difficult for pilots, and their level of cooperation in this study was remarkable, given the circumstances. Additional work needs to be done in the design of an MT test that can be easily used on the flight deck, and that can be used to give pilots on-line feedback about their state of preparedness to process complex information. If pilots do discover, in the course of flying, that they are generating significantly lower scores, countermeasures to fatigue should be implemented. Naps may be problematic because of the inertia effect after sudden arousal in the context of an emergency. However, there are methods for modifying MT programs that will not only assess levels of arousal but may be used to maintain or elevate them. MT modules should be built into the instrument panel to allow for simple and easy access to the procedure for the purpose of developing an individual pilot index. Each pilot’s bidding for pairings should be related to that individual pilot’s index for each pairing.

5 RECOMMENDATIONS

1. An individual multitasking index for each pilot should be developed through systematic collection of data during all flights. Periodic feedback of each pilot’s performance relative to that index should be used by that pilot to make an objective assessment of his or her fatigue.

2. A multitasking procedure should be developed that can be used as an index of fatigue, independently of EEG and as a countermeasure for fatigue during flights.

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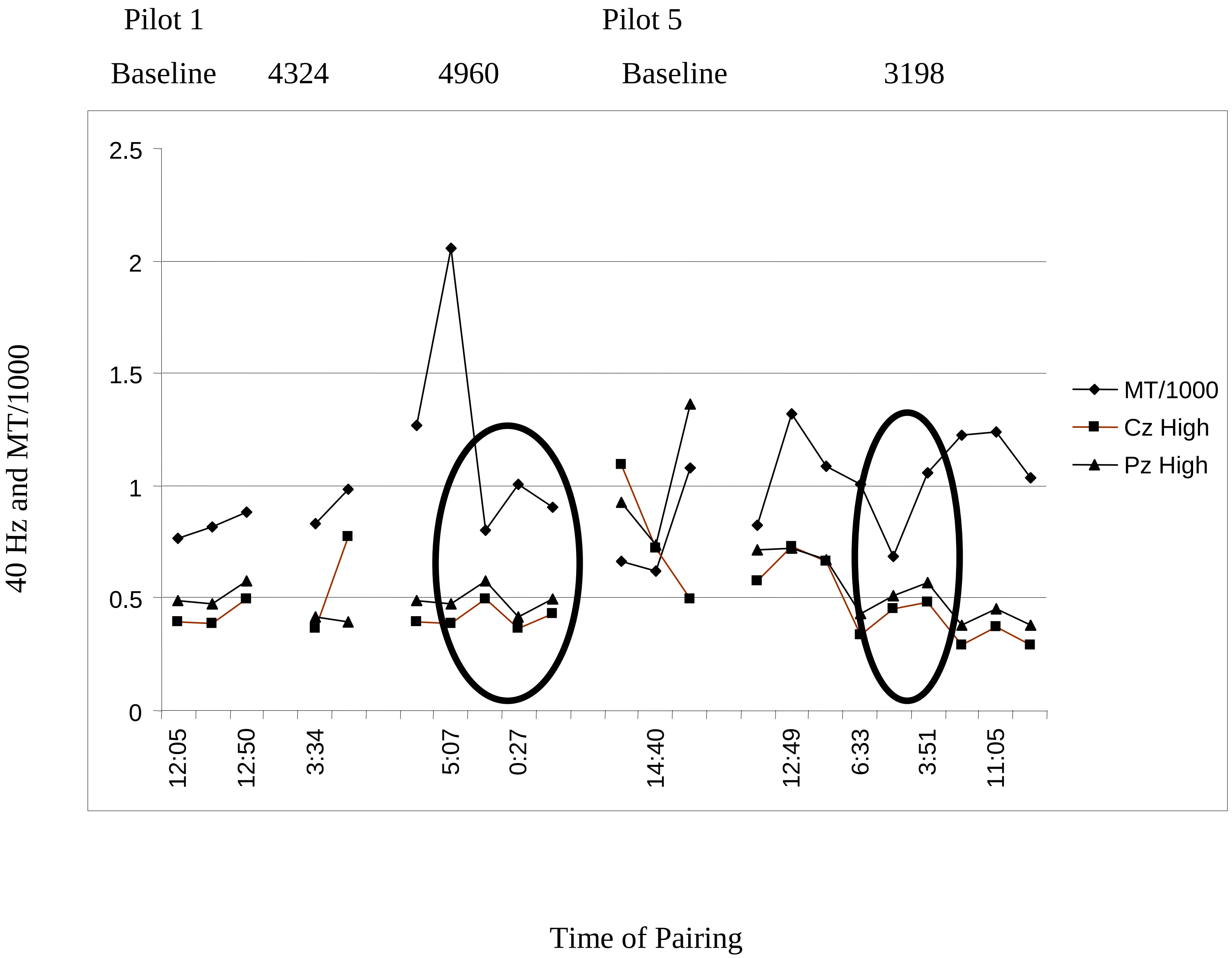
Appendix A

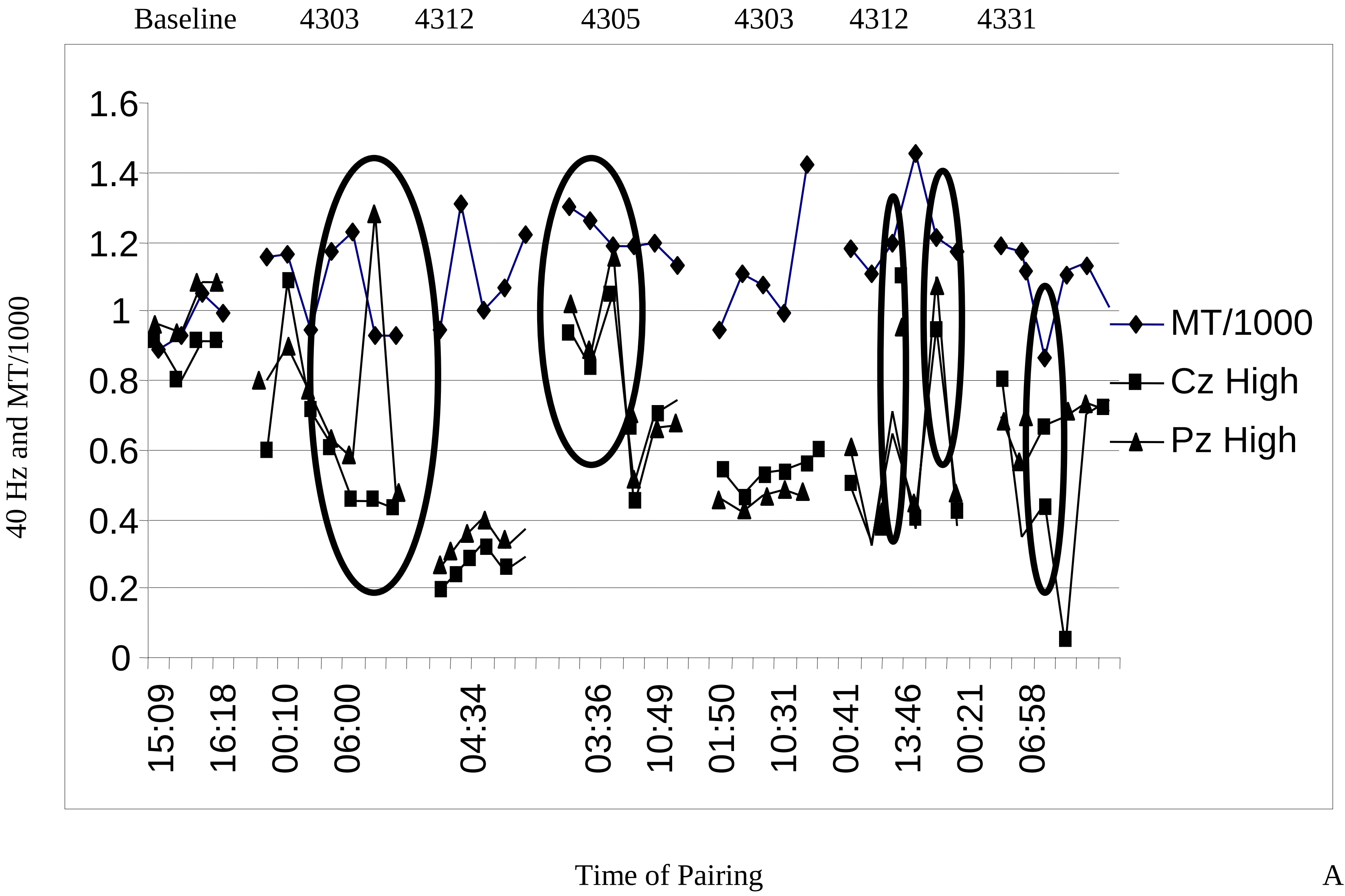
Multitasking and Gamma

Pilot 1 & 5

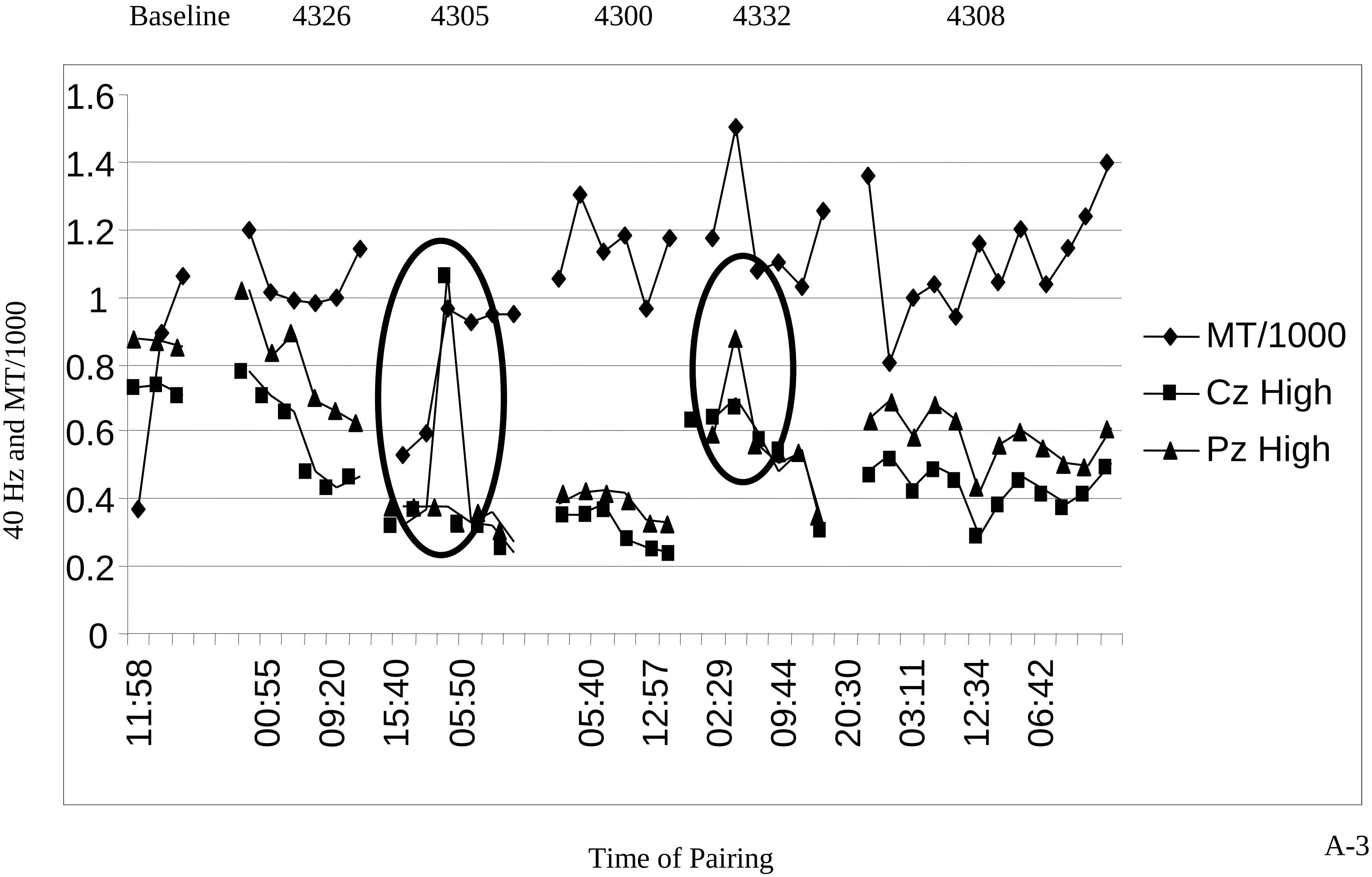


Pilot 1
Pilot 5
Baseline
4324
4960
Baseline
3198
40 Hz and MT/1000
2.5
2
1.5
1
0.5
0
12:05
12:50
3:34
5:07
0:27
14:40
12:49
6:33
3:51
11:05
MT/1000
Cz High
Pz High
Time of Pairing

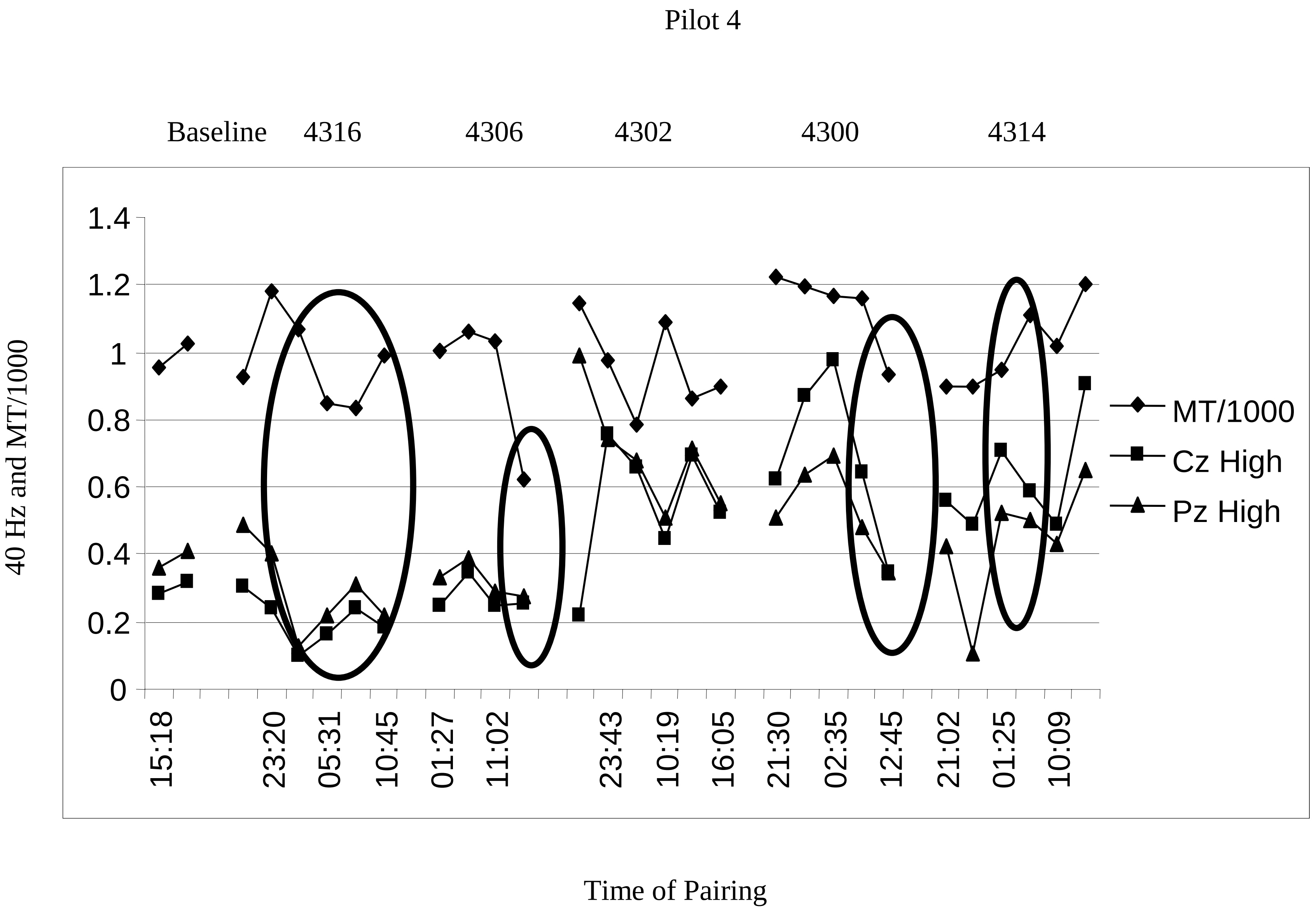
Pilot 2


Baseline
4303
4312
4305
4303
4312
4331
40 Hz and MT/1000
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
15:09
16:18
00:10
06:00
04:34
03:36
10:49
01:50
10:31
00:41
13:46
00:21
06:58
MT/1000
Cz High
Pz High
Time of Pairing

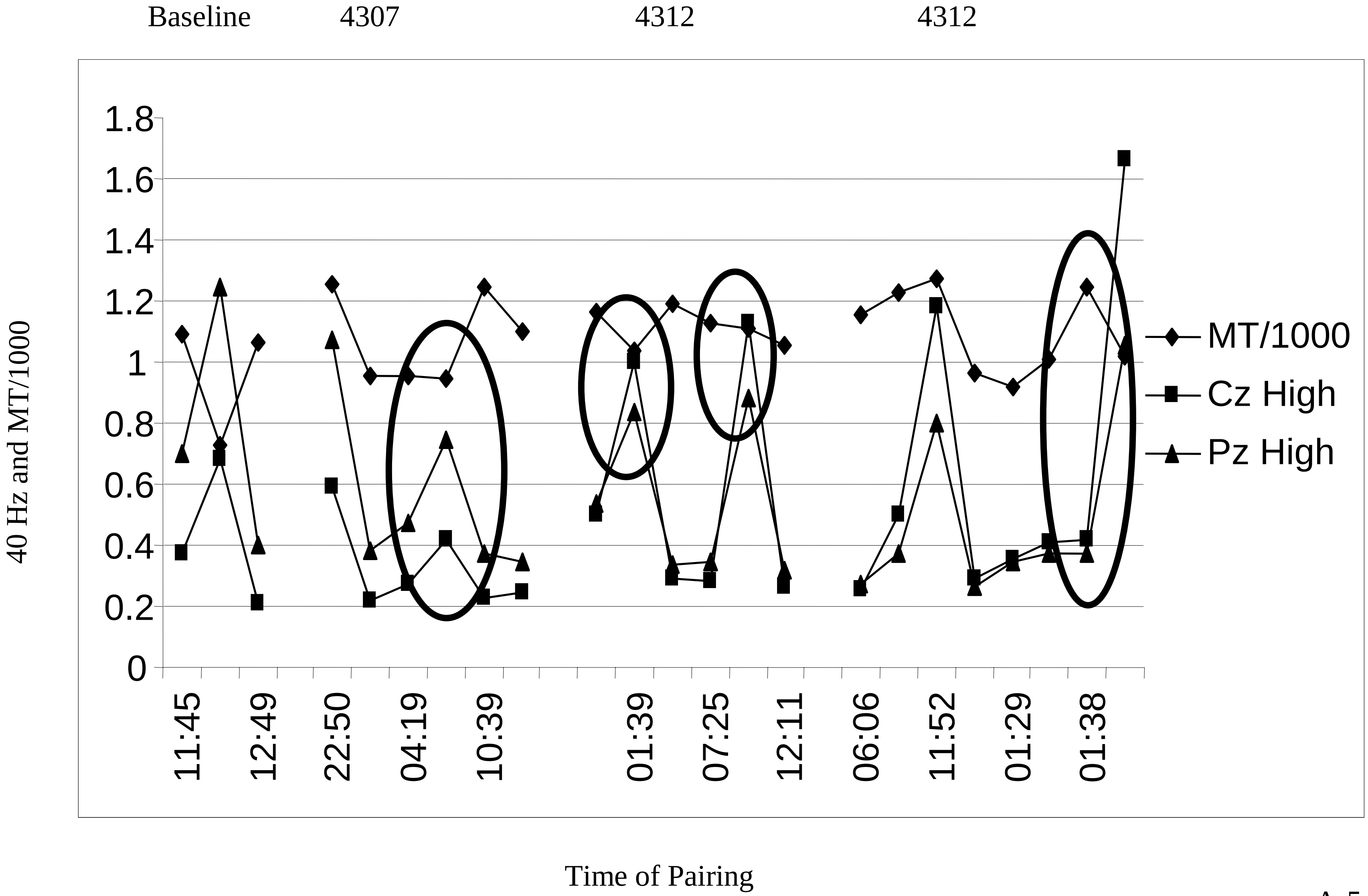
Pilot 3



Baseline
4326
4305
4300
4332
4308
40 Hz and MT/1000
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
11:58
00:55
09:20
15:40
05:50
05:40
12:57
02:29
09:44
20:30
03:11
12:34
06:42
MT/1000
Cz High
Pz High
Time of Pairing


Pilot 4
Baseline
4316
4306
4302
4300
4314
1.4
1.2
1
0.8
0.6
0.4
0.2
0
40 Hz and MT/1000
15:18
23:20
05:31
10:45
01:27
11:02
23:43
10:19
16:05
21:30
02:35
12:45
21:02
01:25
10:09
MT/1000
Cz High
Pz High
Time of Pairing

Pilot 6


Baseline
4307
4312
4312
40 Hz and MT/1000
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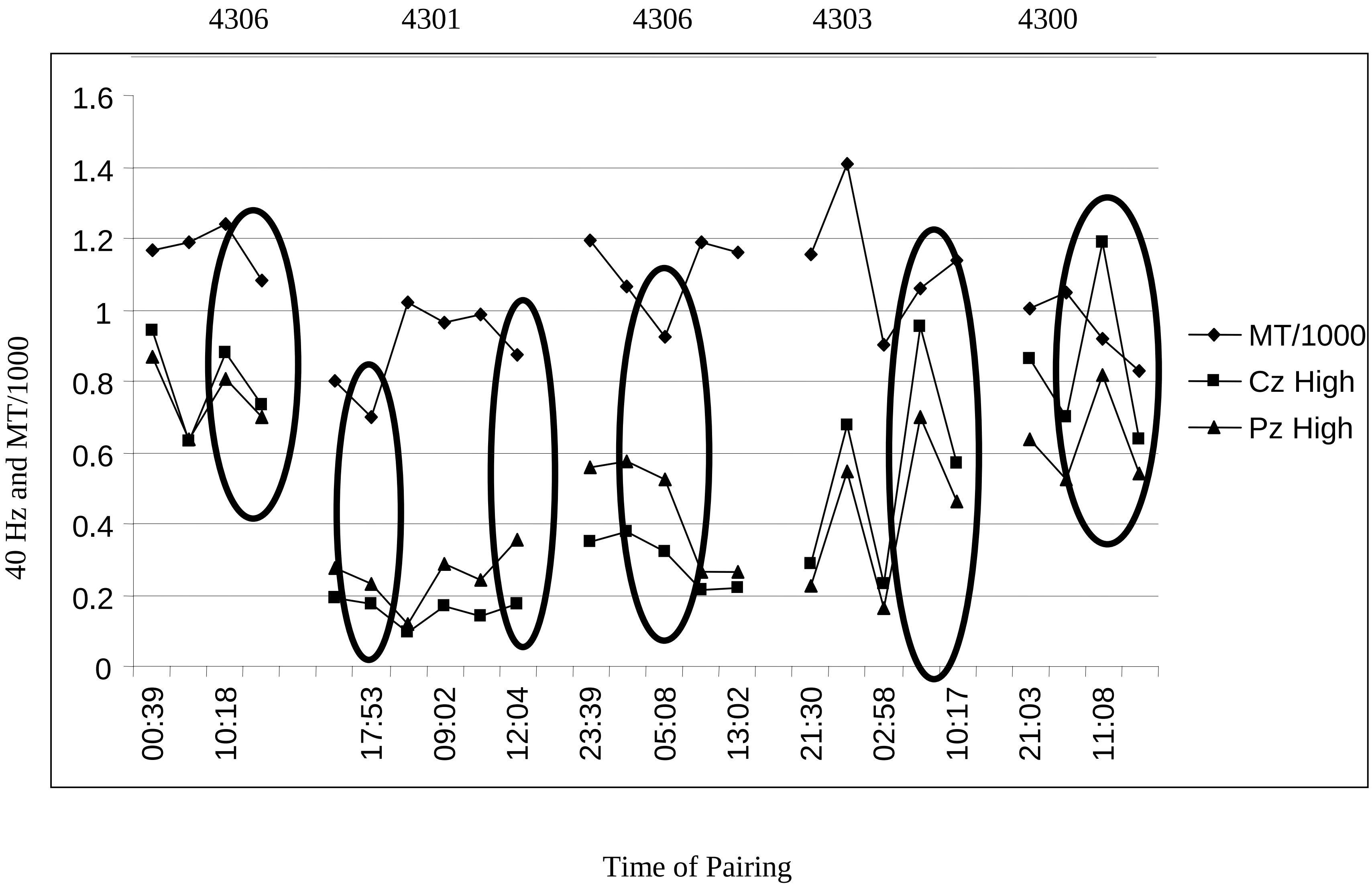
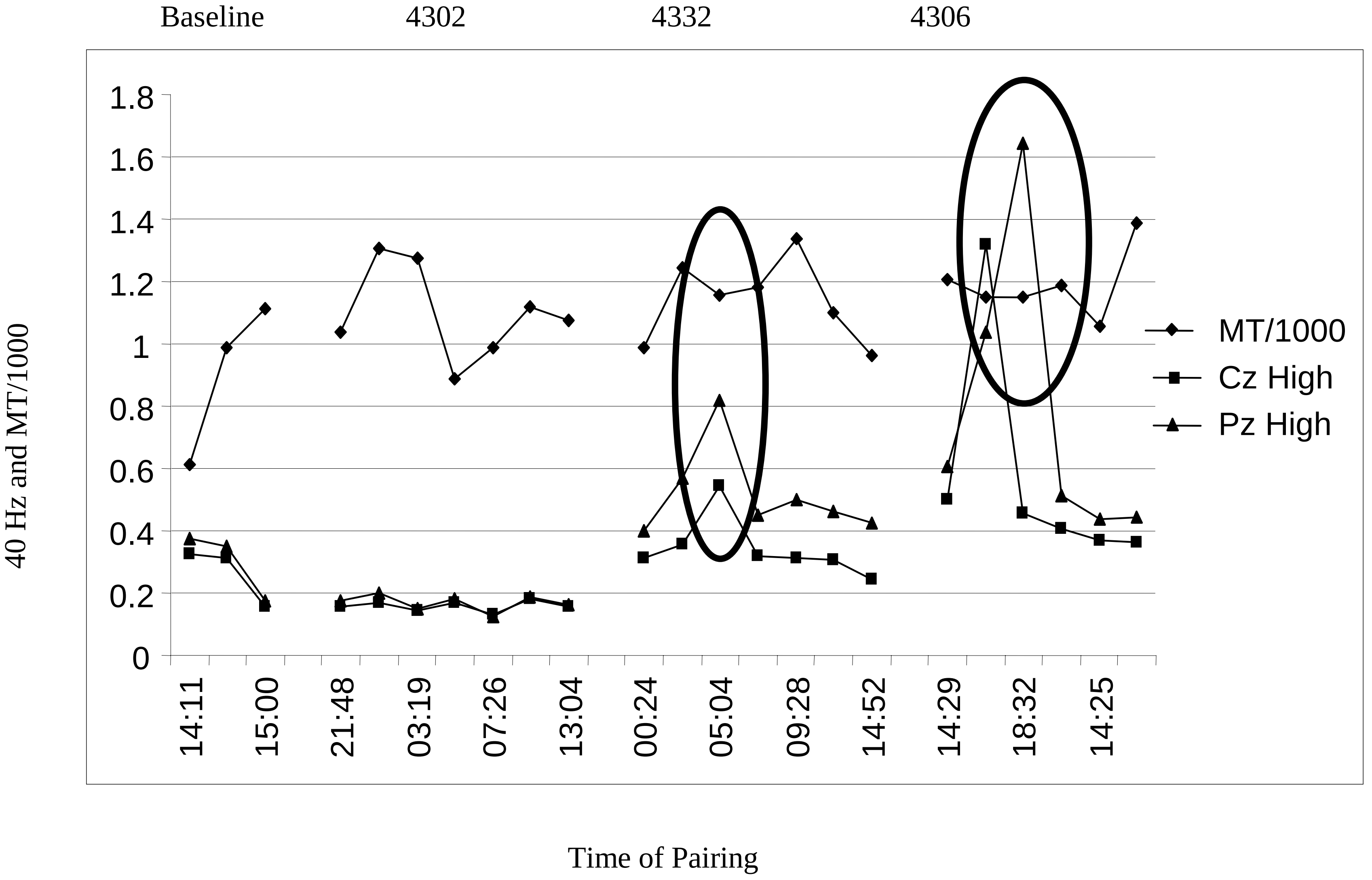
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
11:45
12:49
22:50
04:19
10:39
01:39
07:25
12:11
06:06
11:52
01:29
01:38
MT/1000
Cz High
Pz High
Time of Pairing

Pilot 7

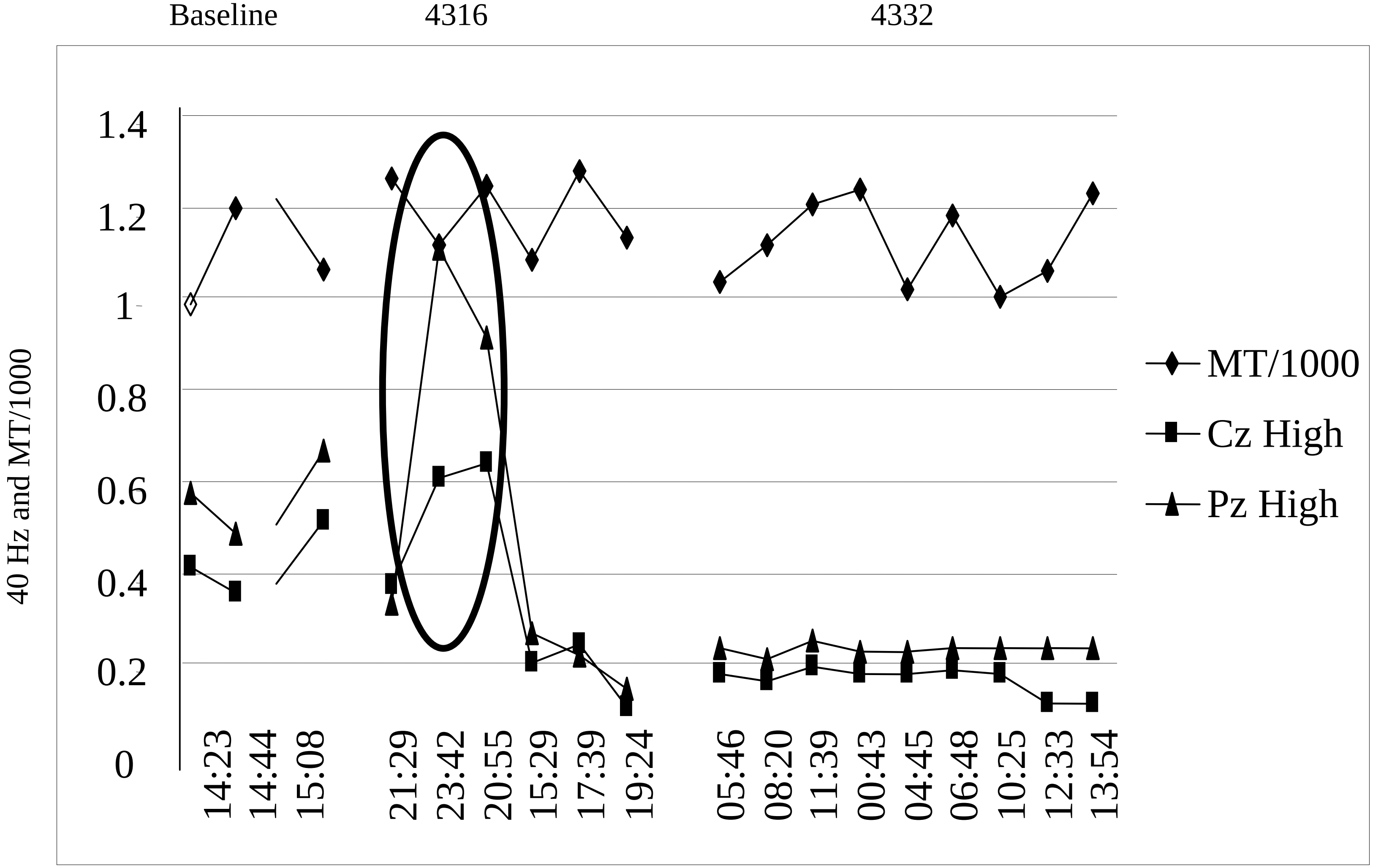

4306
4301
4306
4303
4300
40 Hz and MT/1000
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
00:39
10:18
17:53
09:02
12:04
23:39
05:08
13:02
21:30
02:58
10:17
21:03
11:08
MT/1000
Cz High
Pz High
Time of Pairing

Pilot 9



Baseline
4302
4332
4306
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
14:11
15:00
21:48
03:19
07:26
13:04
00:24
05:04
09:28
14:52
14:29
18:32
14:25
MT/1000
Cz High
Pz High
40 Hz and MT/1000
Time of Pairing

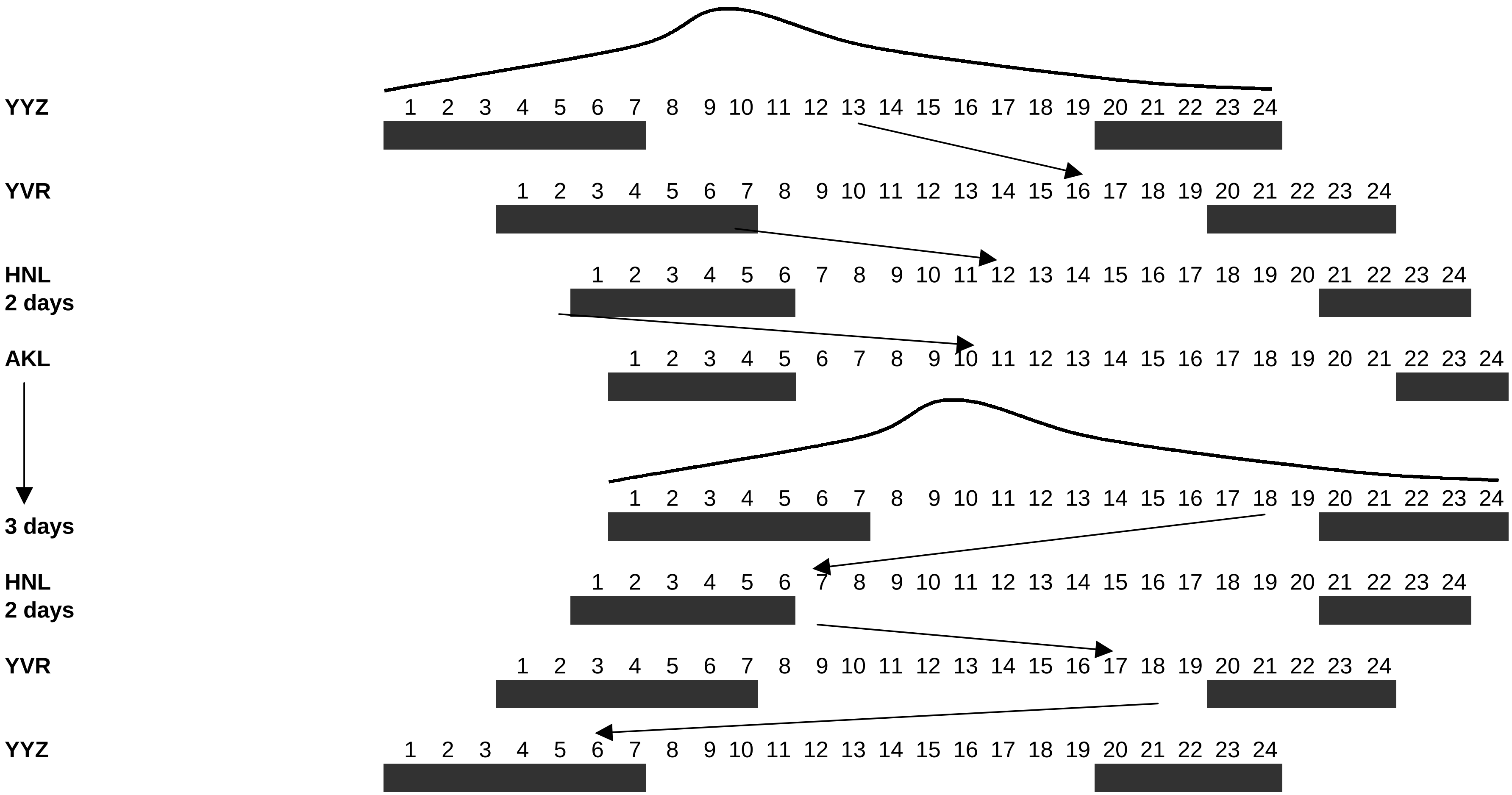
Pilot 10


Baseline
4316
4332
40 Hz and MT/1000
1.4
1.2
1
0.8
0.6
0.4
0.2
0
14:23
14:44
15:08
21:29
23:42
20:55
15:29
17:39
19:24
05:46
08:20
11:39
00:43
04:45
06:48
10:25
12:33
13:54
MT/1000
Cz High
Pz High

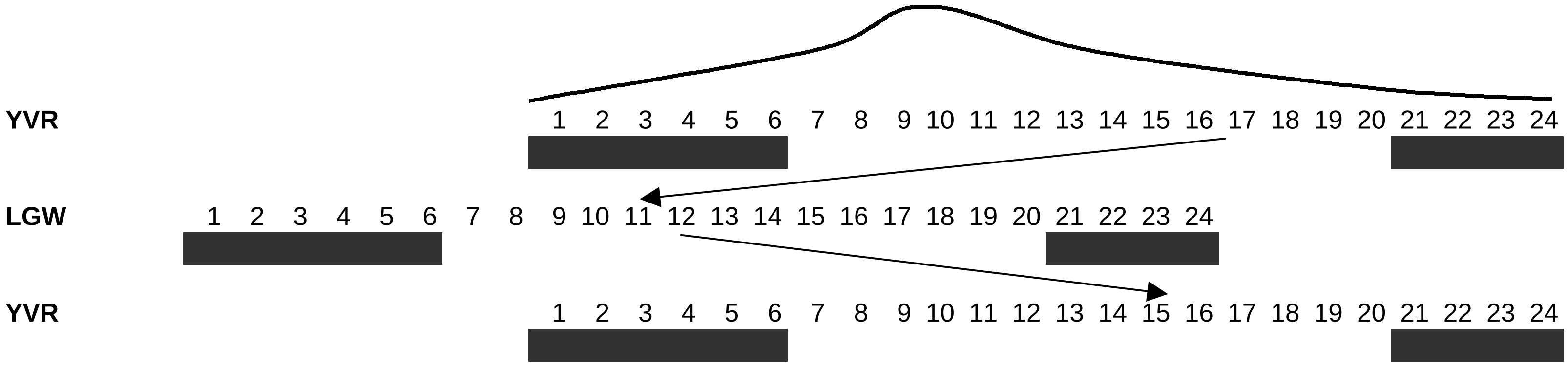
Appendix B

Circadian Periods for Pairings

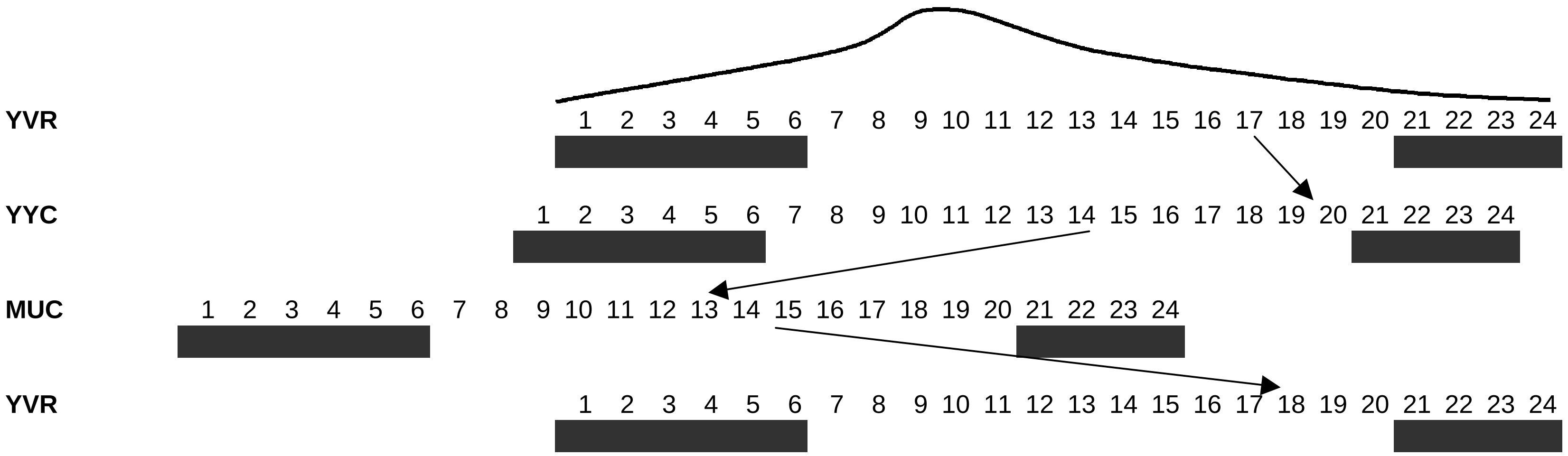
Pairing 3198



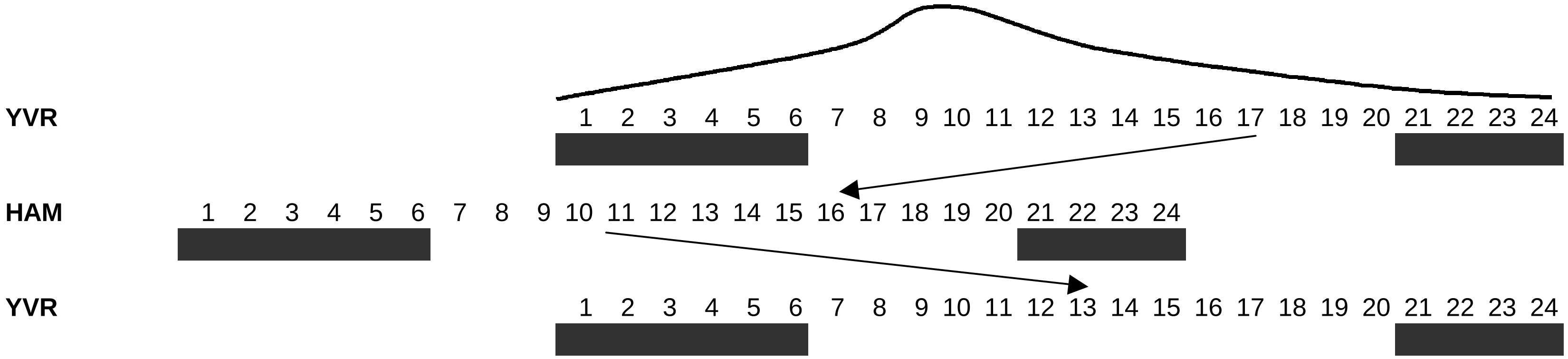
Pairing 4300



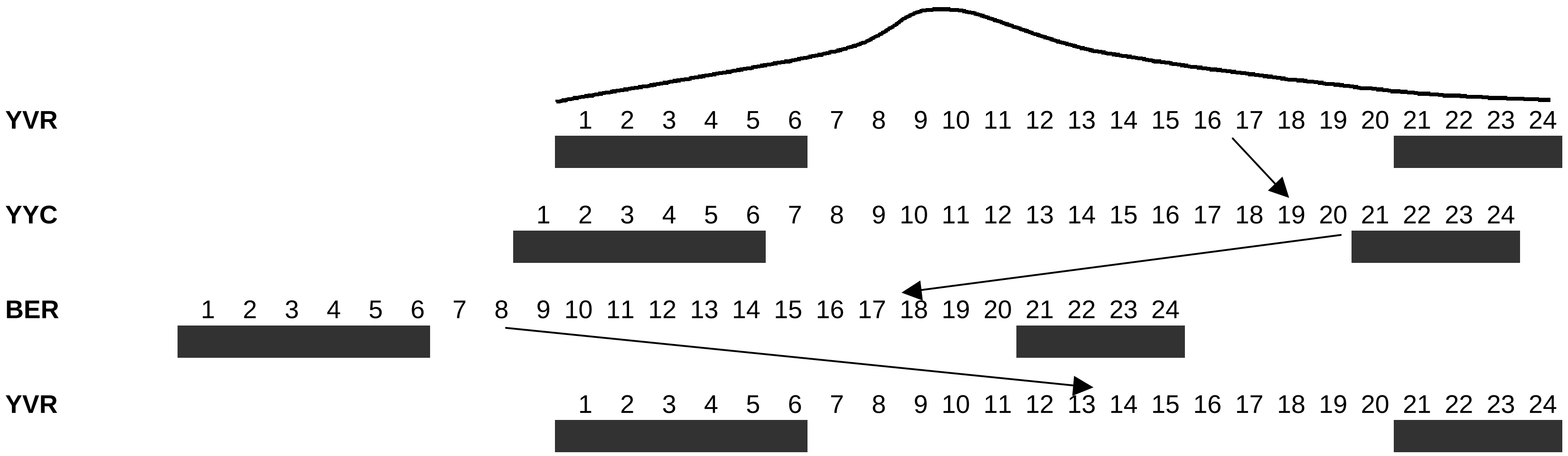
Pairing 4301



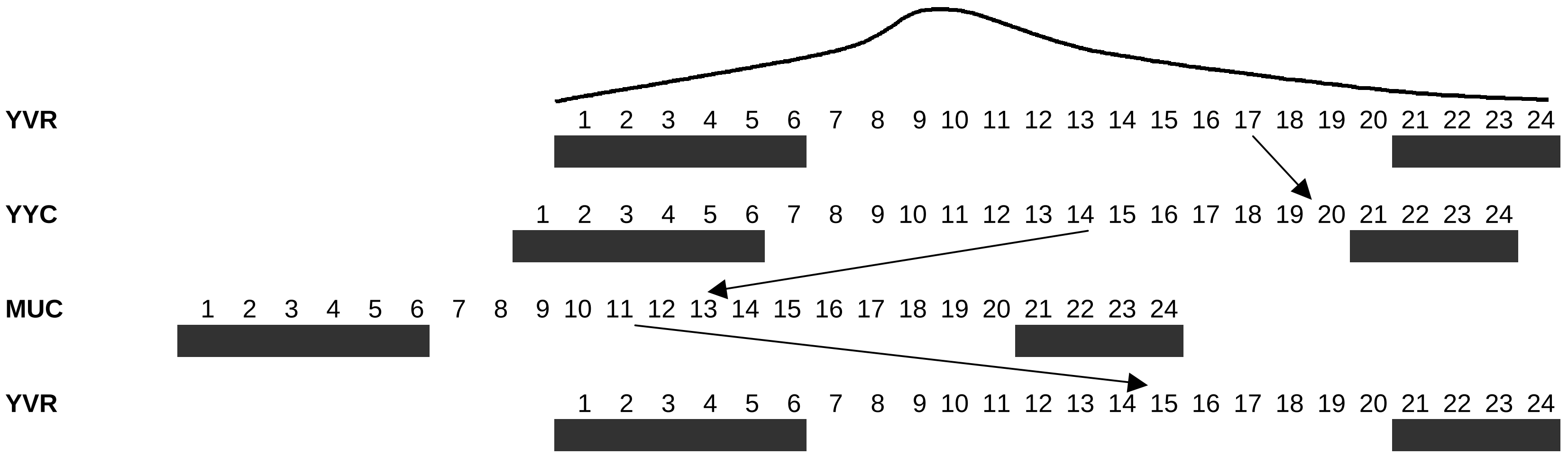
Pairing 4302



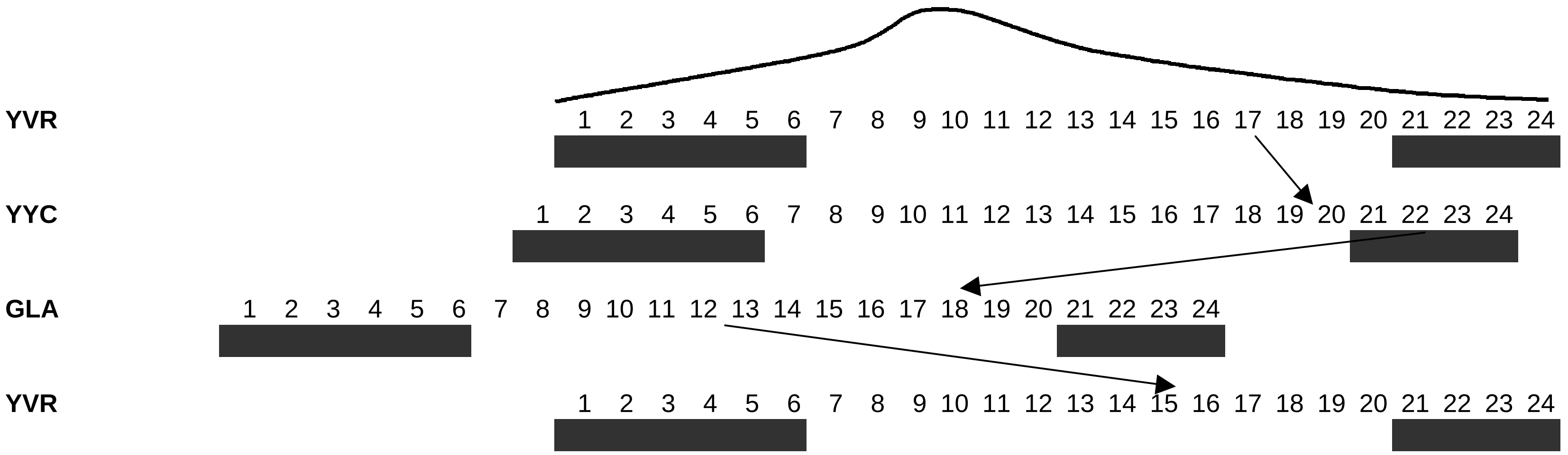
Pairing 4303



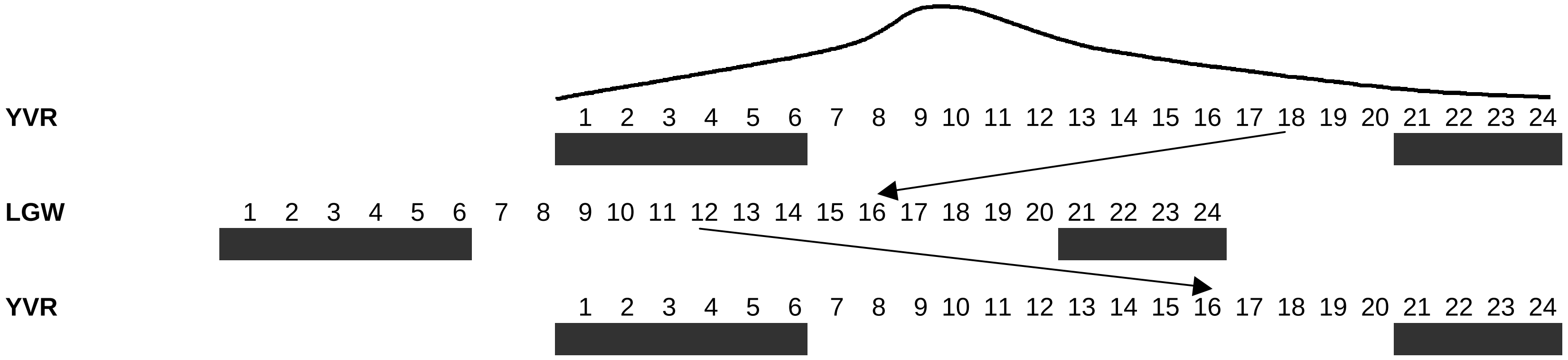
Pairing 4305



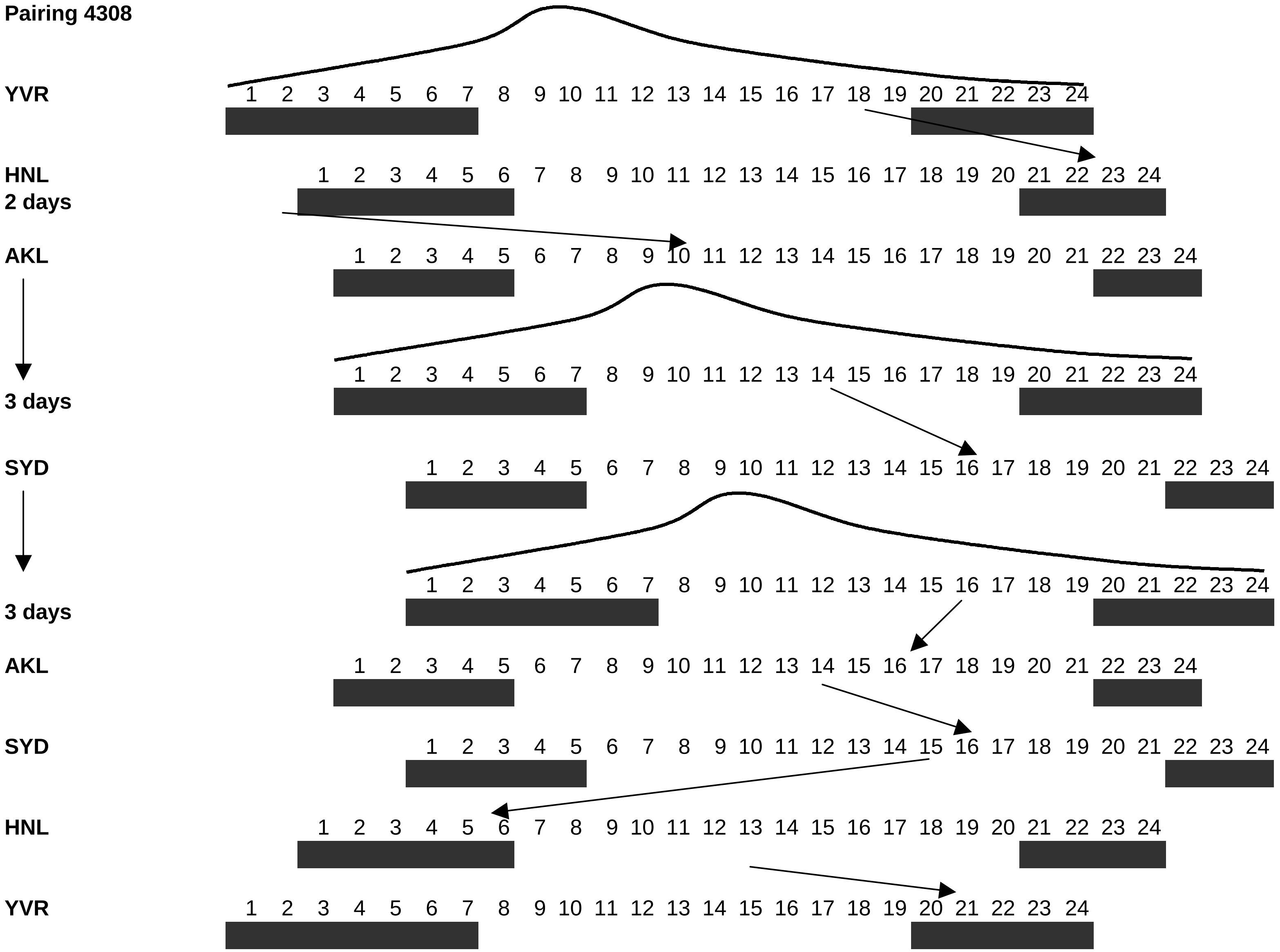
Pairing 4306



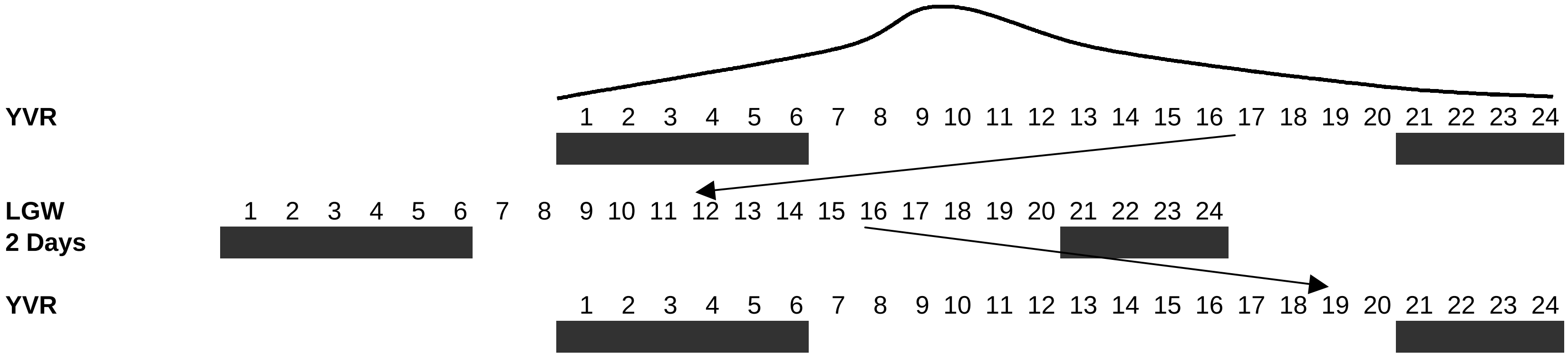
Pairing 4307



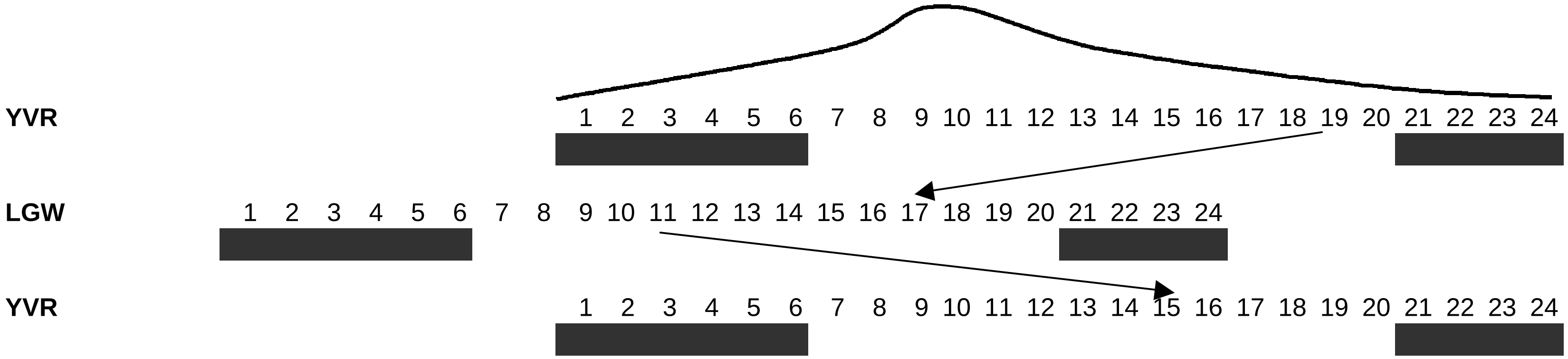
Pairing 4308



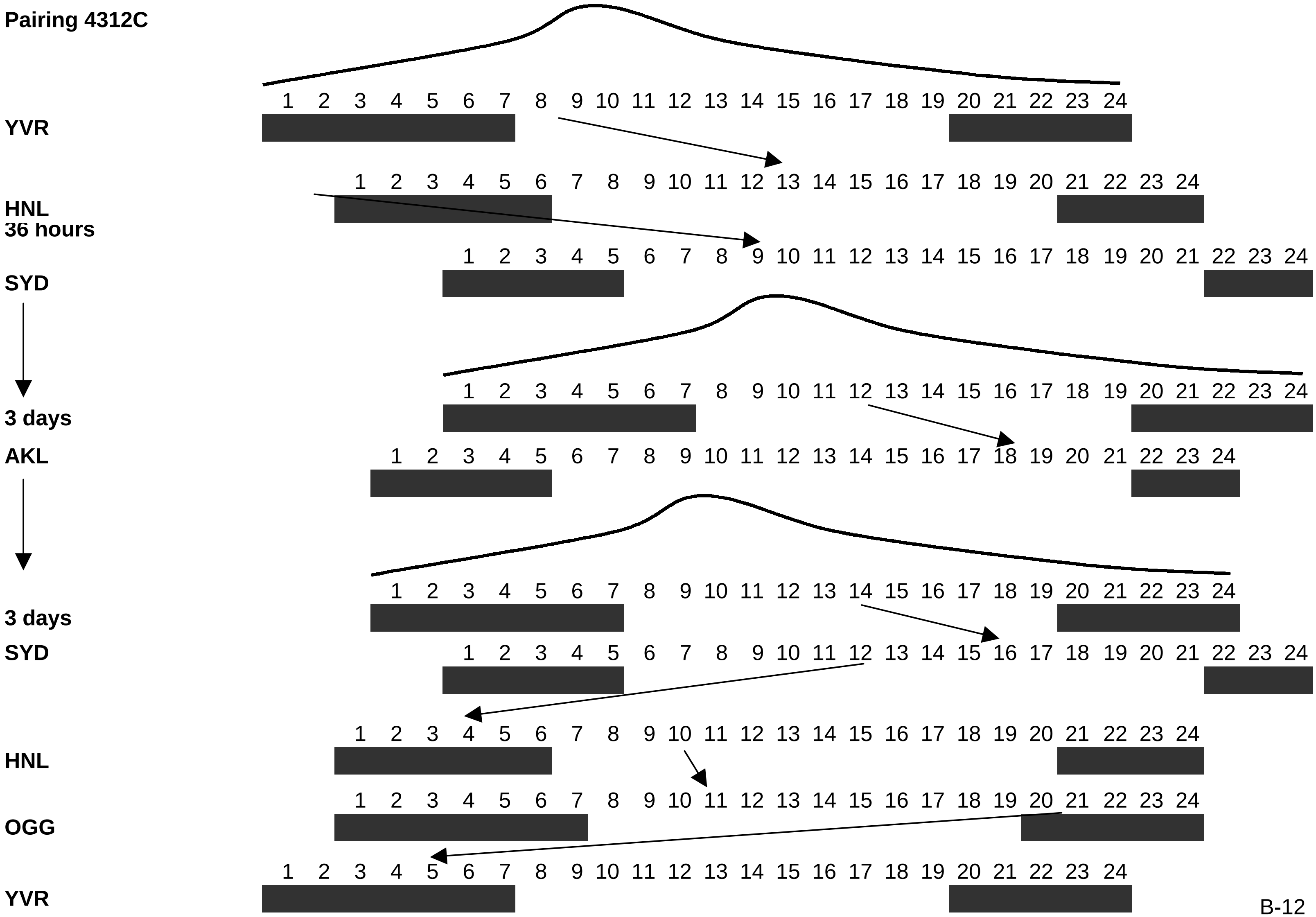
Pairing 4312A



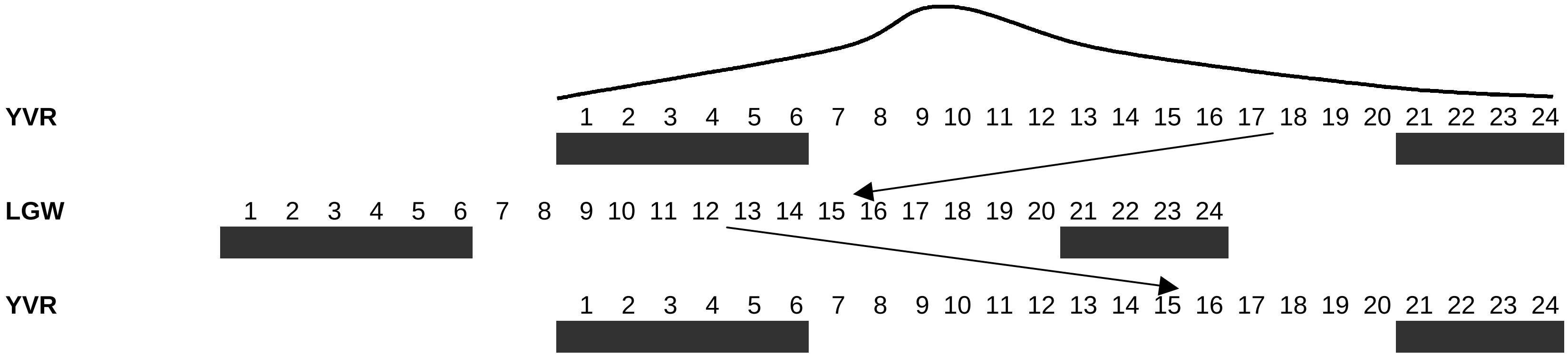
Pairing 4312B



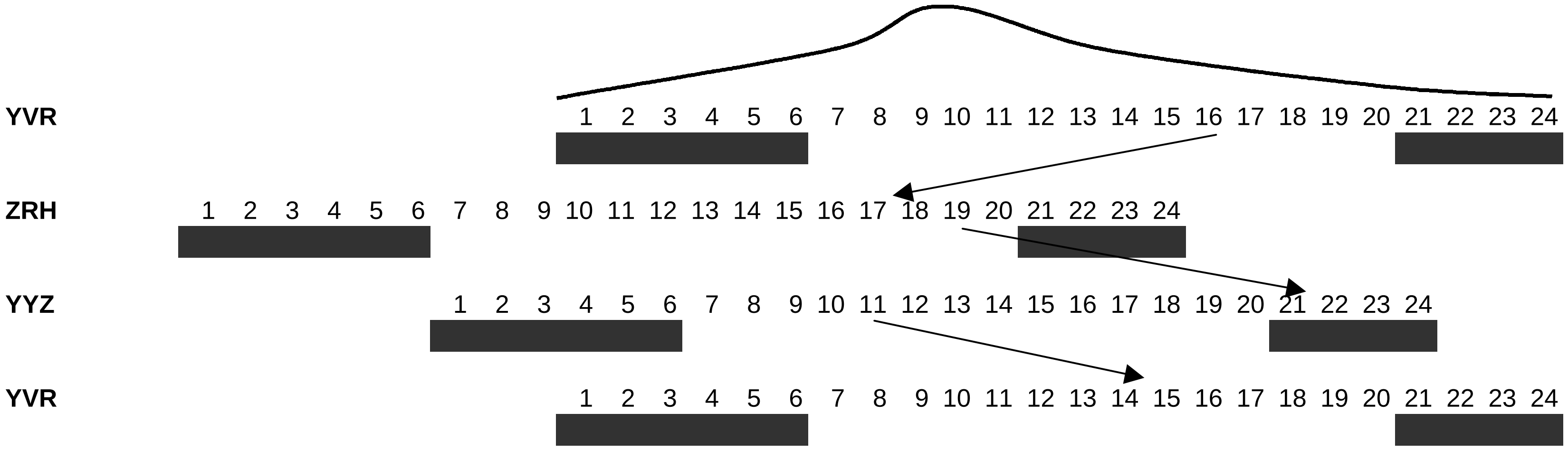
Pairing 4312C



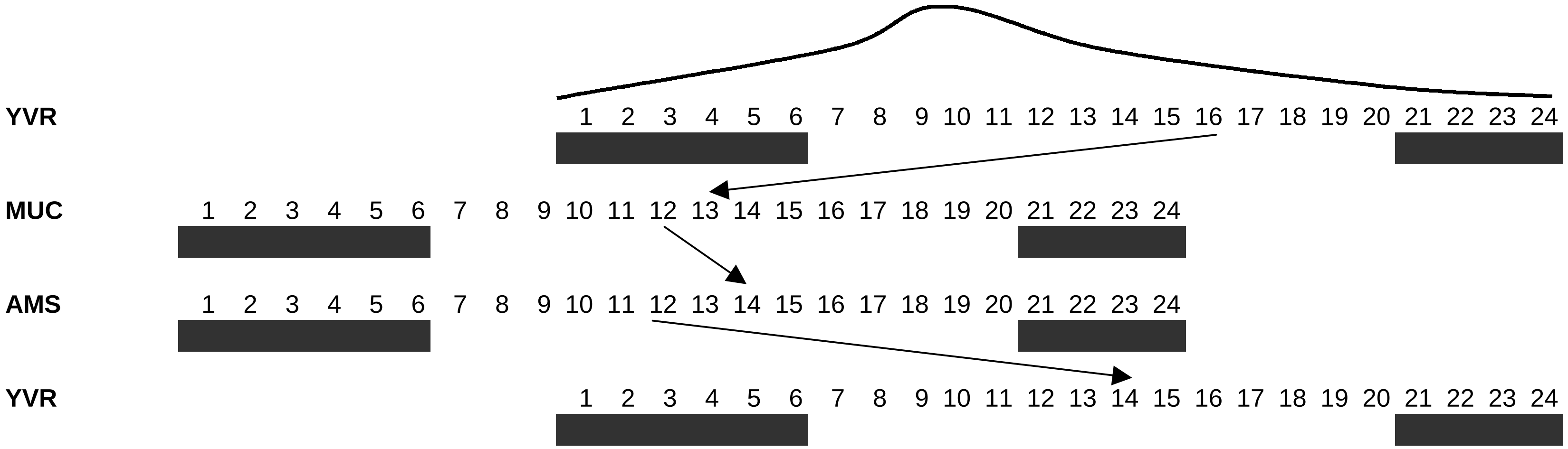
Pairing 4314



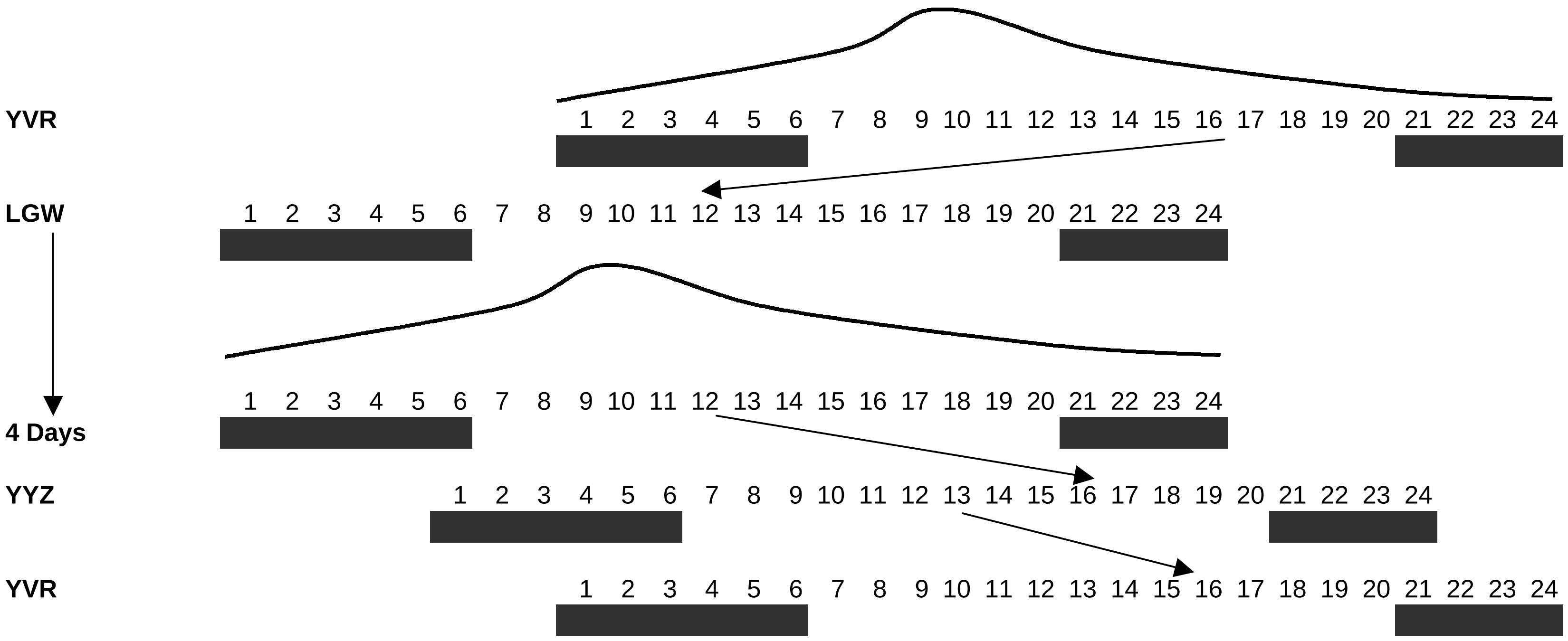
Pairing 4315



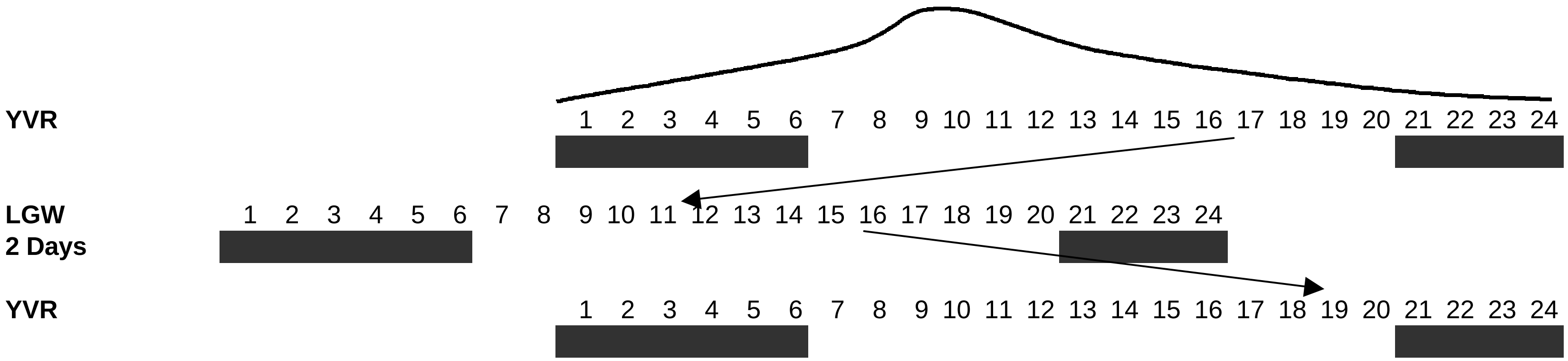
Pairing 4316



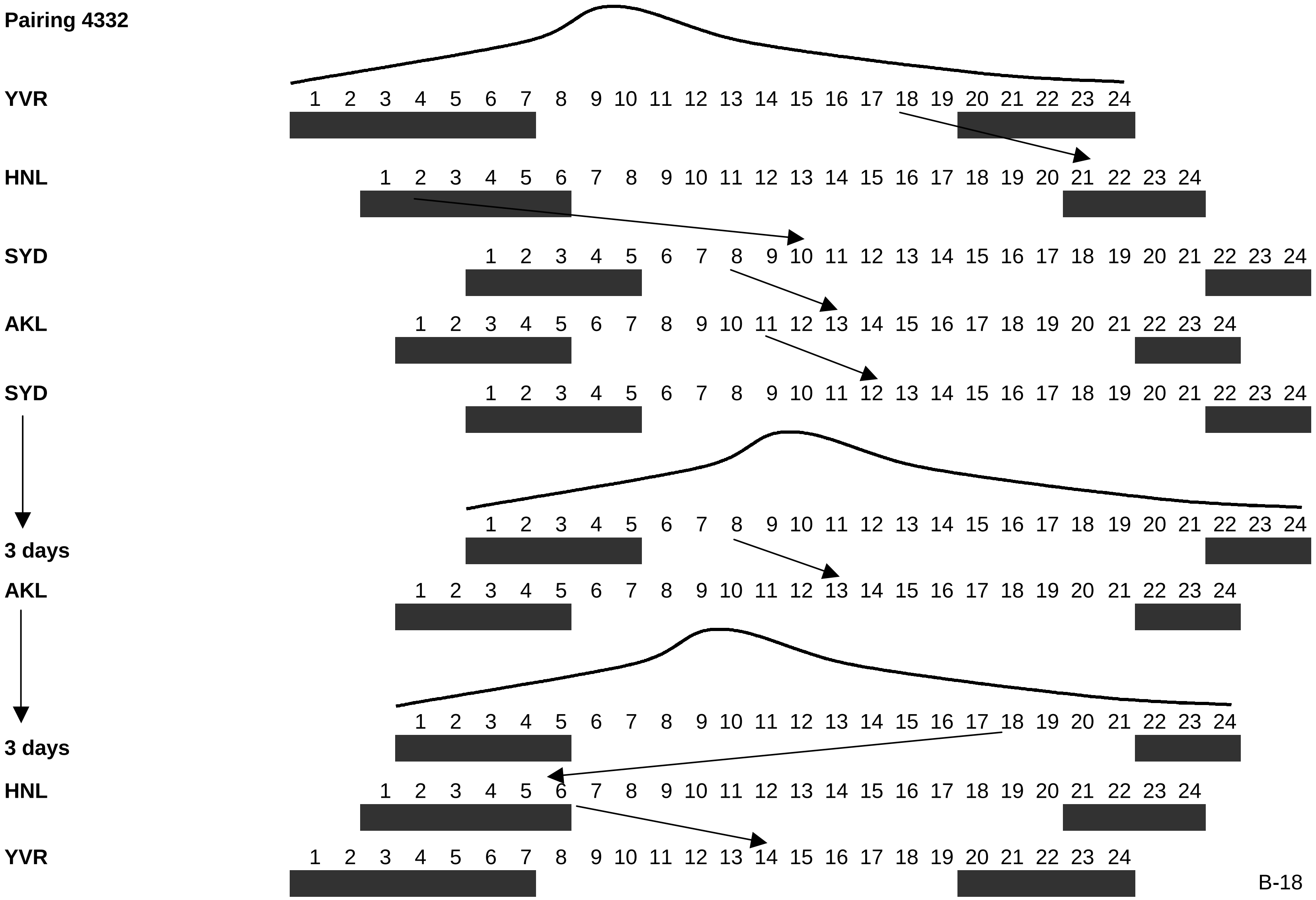
Pairing 4324



Pairing 4331

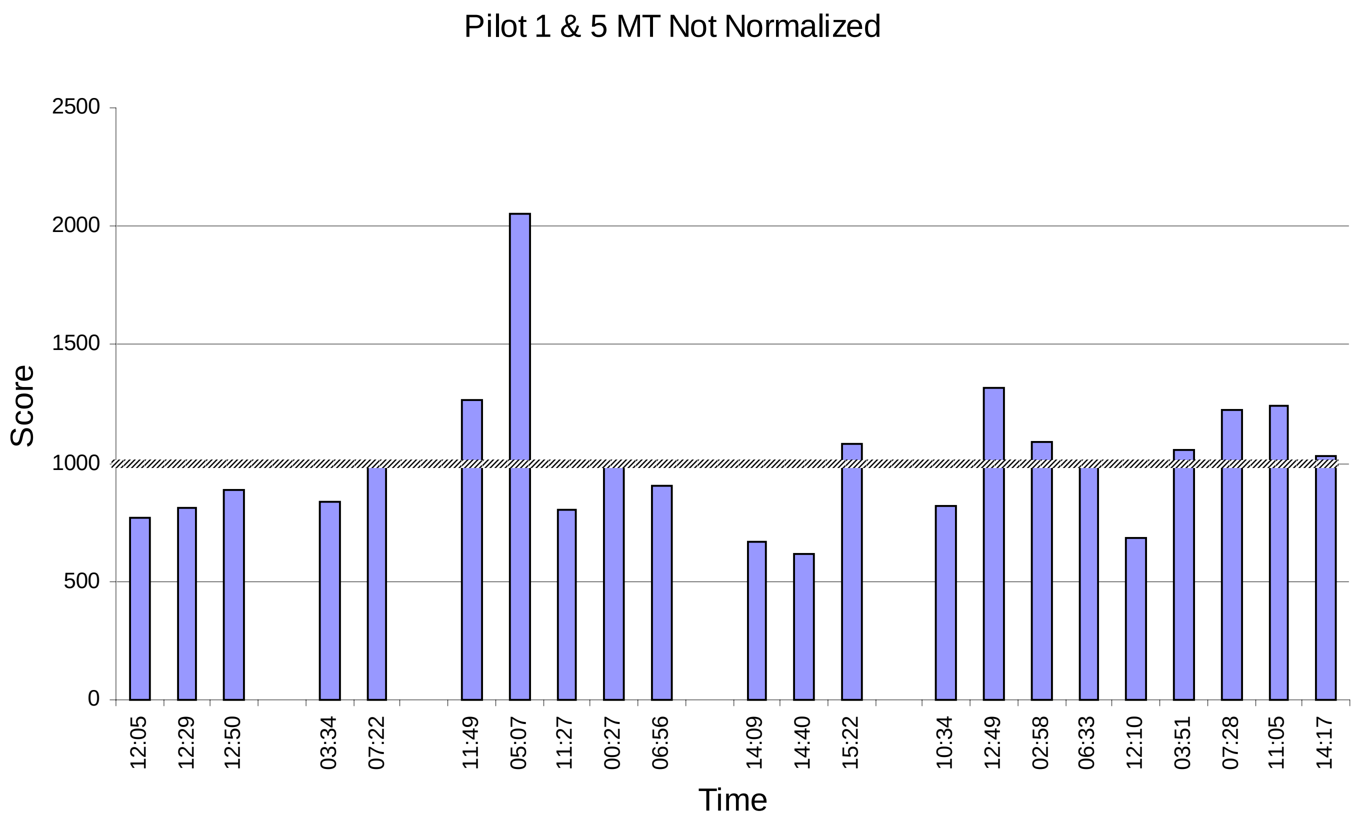


Pairing 4332

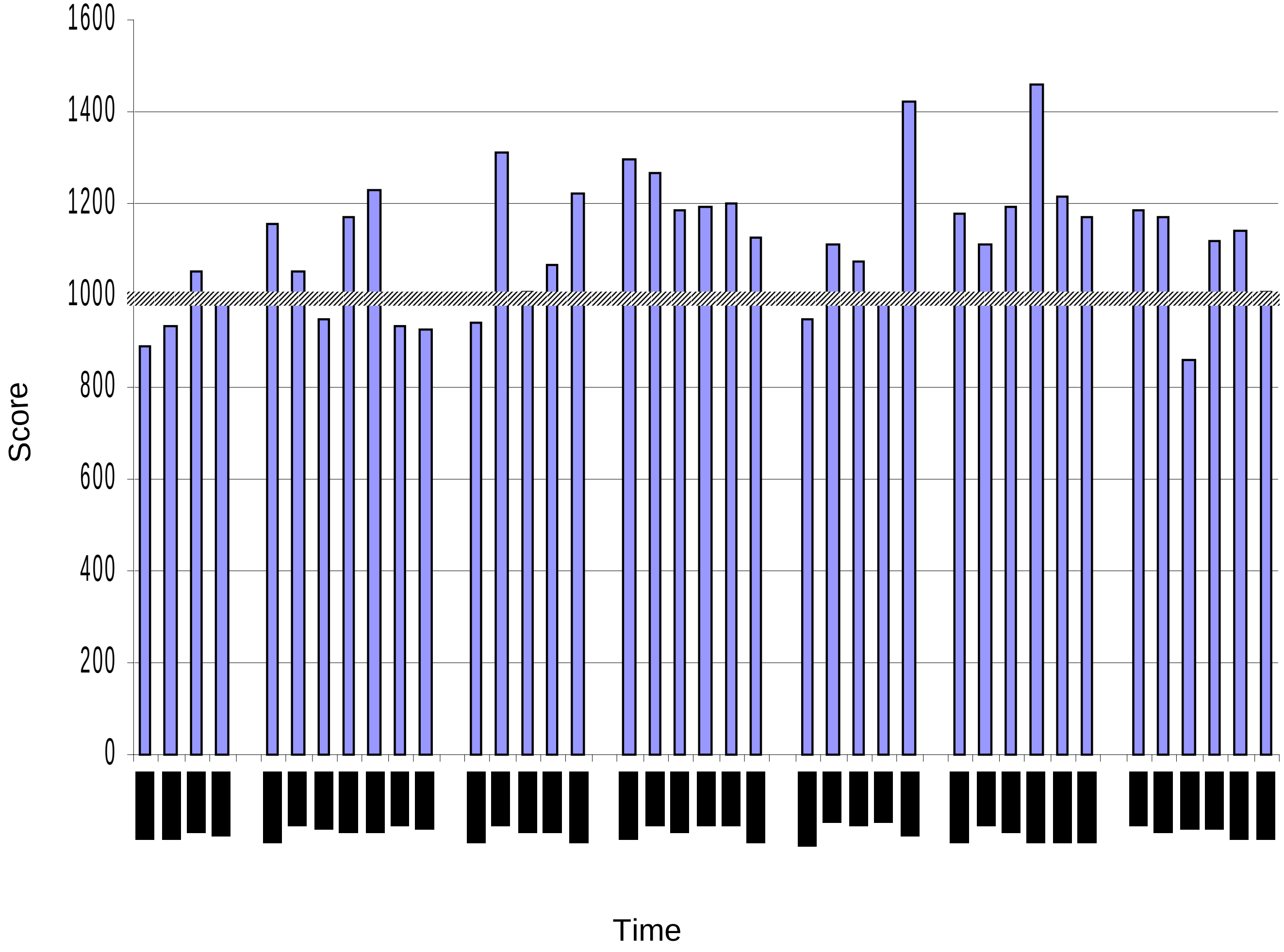


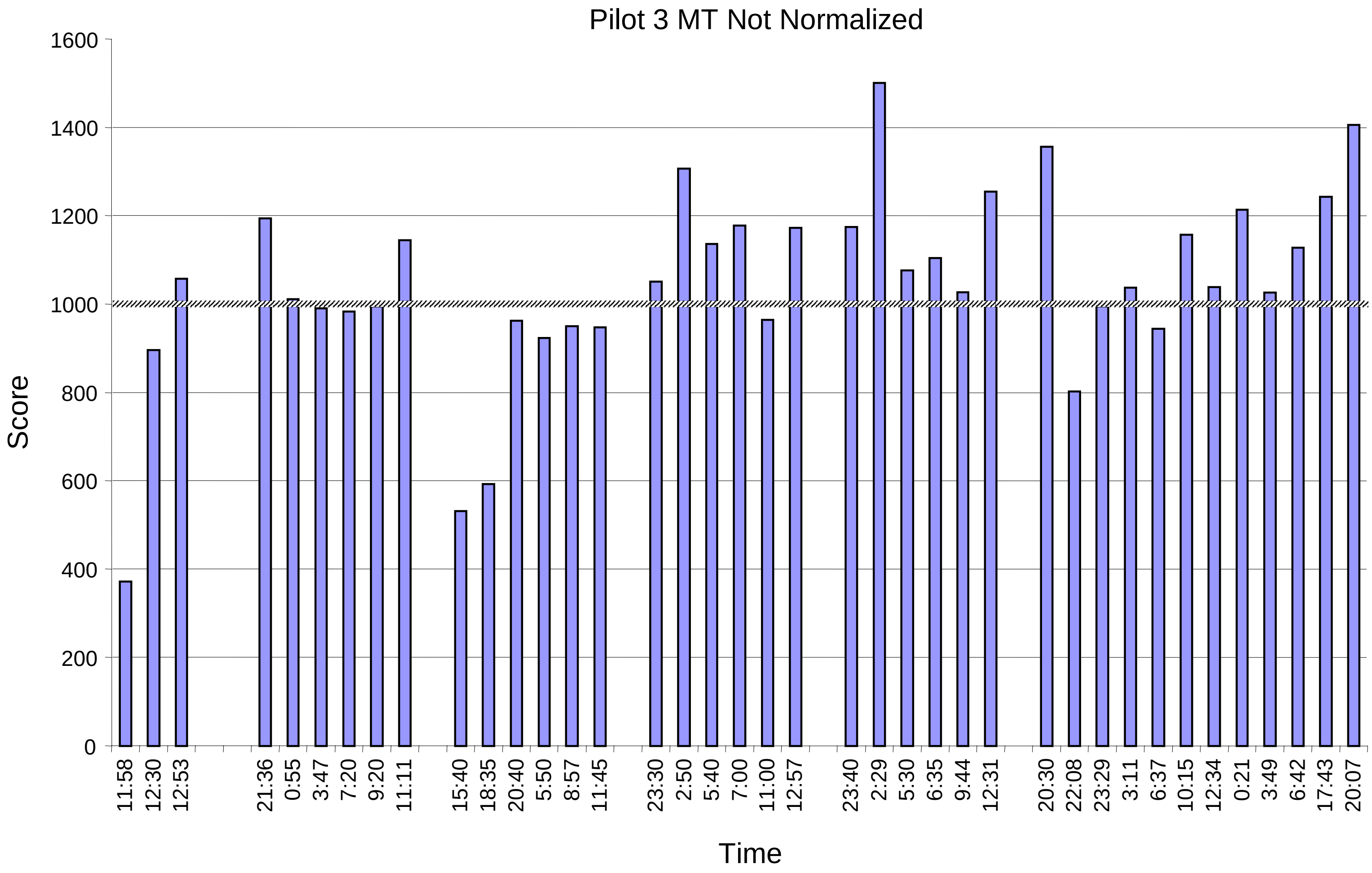
Appendix C

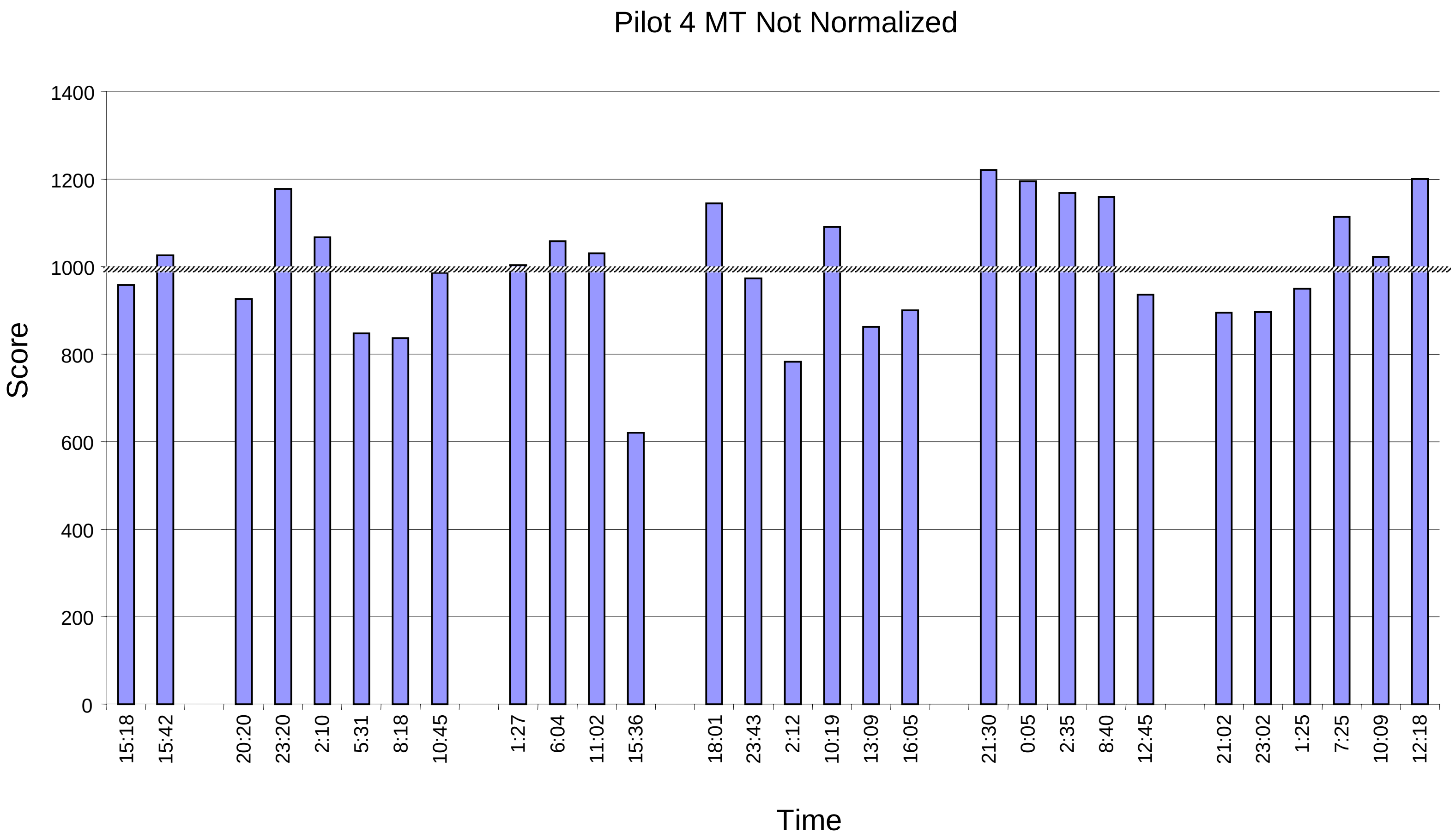
Multitasking Scores


Pilot 1 & 5 MT Not Normalized
Score
2500
2000
1500
1000
500
0
12:05
12:29
12:50
03:34
07:22
11:49
05:07
11:27
00:27
06:56
14:09
14:40
15:22
10:34
12:49
02:58
06:33
12:10
03:51
07:28
11:05
14:17
Time

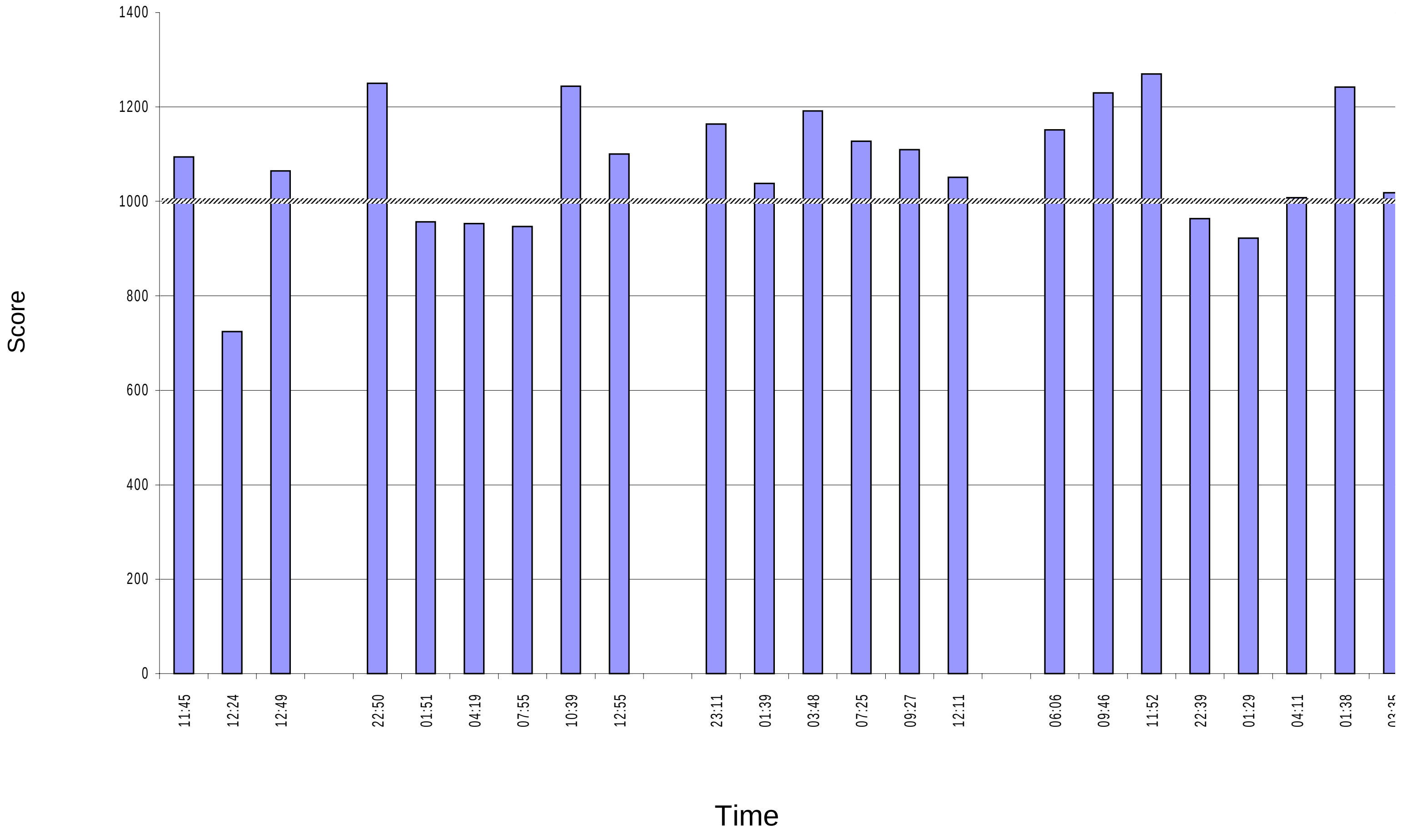
Pilot 2 MT Not Normalized

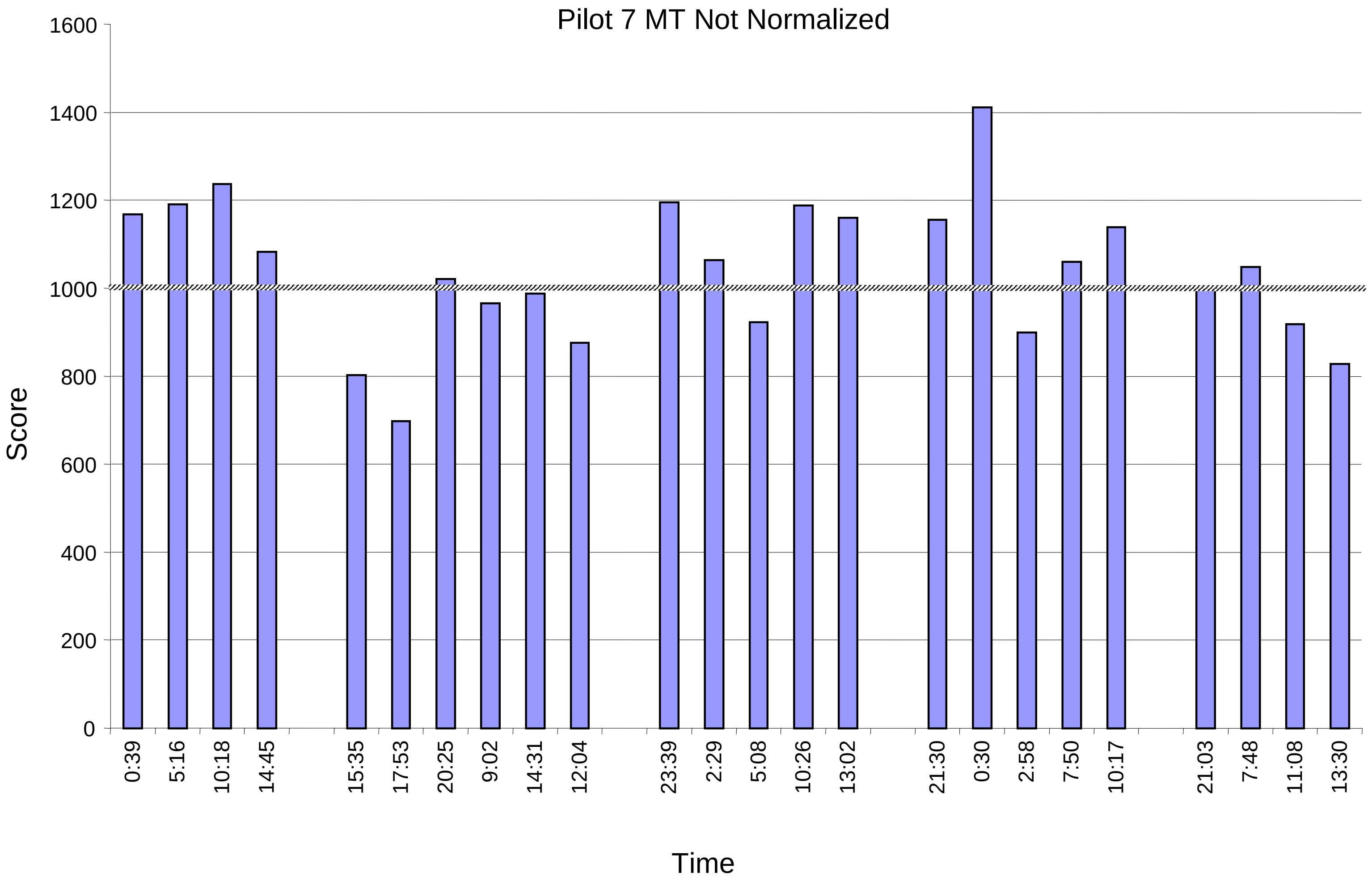


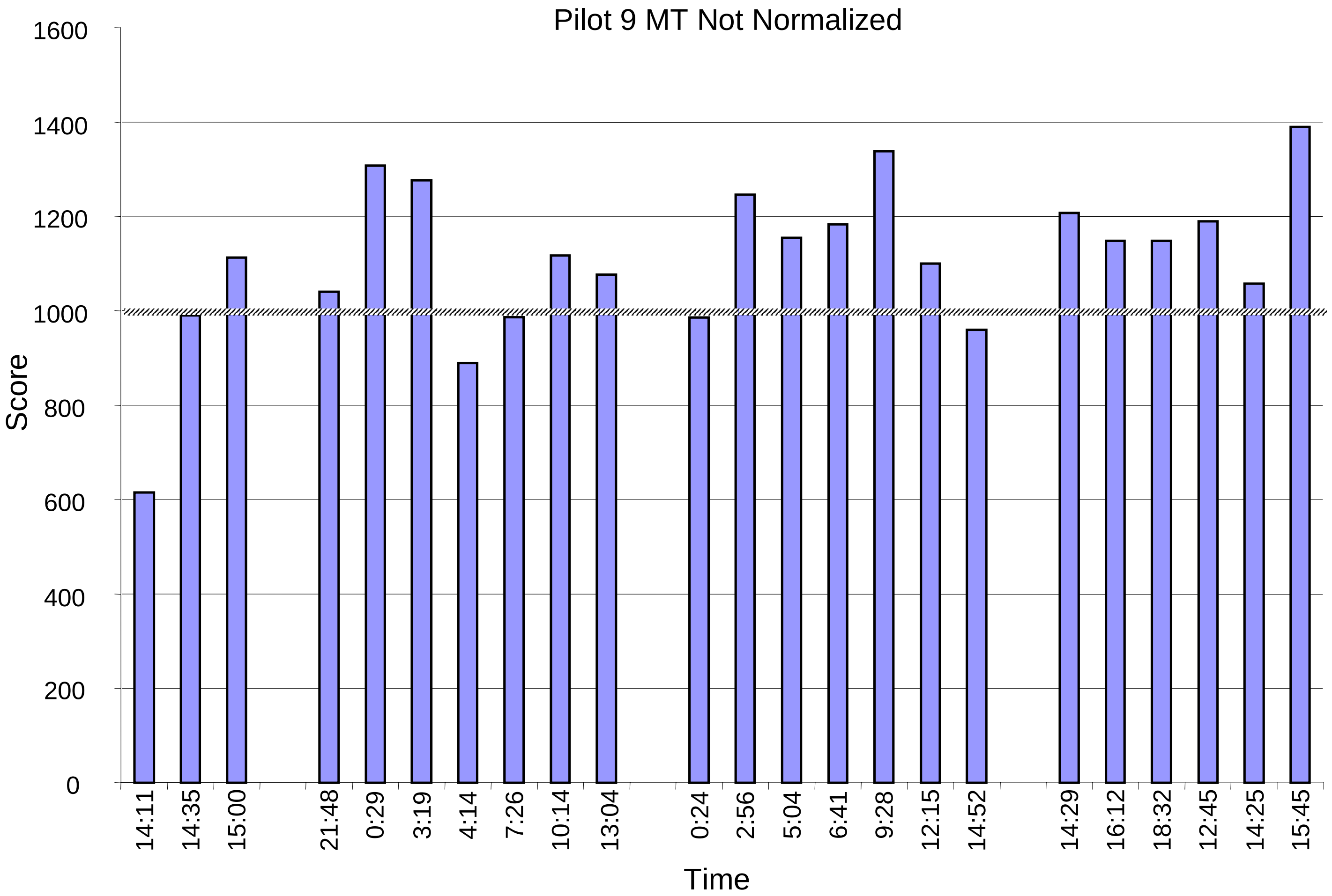

Pilot 3 MT Not Normalized
Score
Time
1600
1400
1200
1000
800
600
400
200
0
11:58
12:30
12:53
21:36
0:55
3:47
7:20
9:20
11:11
15:40
18:35
20:40
5:50
8:57
11:45
23:30
2:50
5:40
7:00
11:00
12:57
23:40
2:29
5:30
6:35
9:44
12:31
20:30
22:08
23:29
3:11
6:37
10:15
12:34
0:21
3:49
6:42
17:43
20:07


Pilot 4 MT Not Normalized
Score
1400
1200
1000
800
600
400
200
0
15:18
15:42
20:20
23:20
2:10
5:31
8:18
10:45
1:27
6:04
11:02
15:36
18:01
23:43
2:12
10:19
13:09
16:05
21:30
0:05
2:35
8:40
12:45
21:02
23:02
1:25
7:25
10:09
12:18
Time

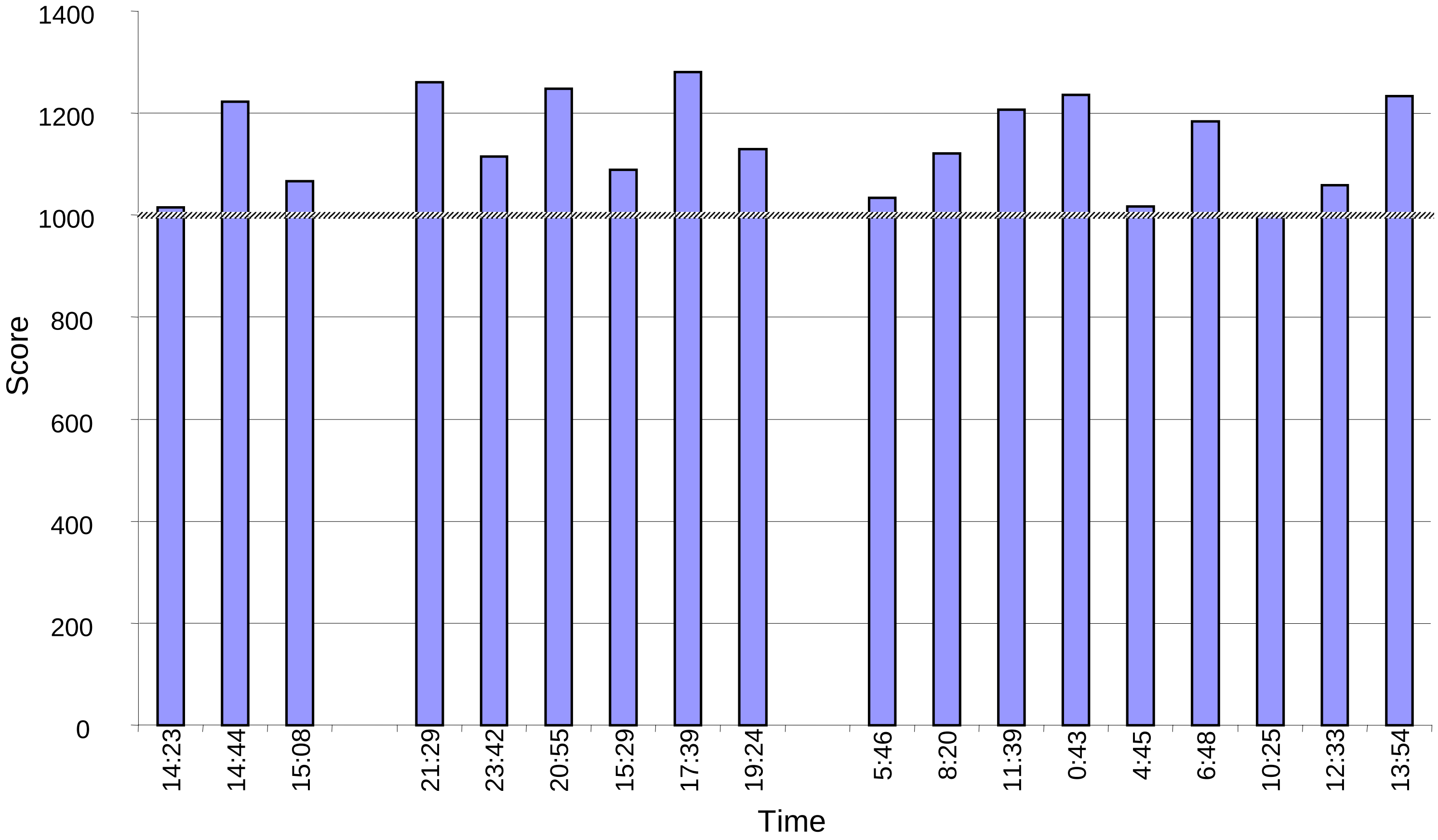
Pilot 6 MT Not Normalized




Pilot 7 MT Not Normalized
Score
1600
1400
1200
1000
800
600
400
200
0
0:39
5:16
10:18
14:45
15:35
17:53
20:25
9:02
14:31
12:04
23:39
2:29
5:08
10:26
13:02
21:30
0:30
2:58
7:50
10:17
21:03
7:48
11:08
13:30
Time

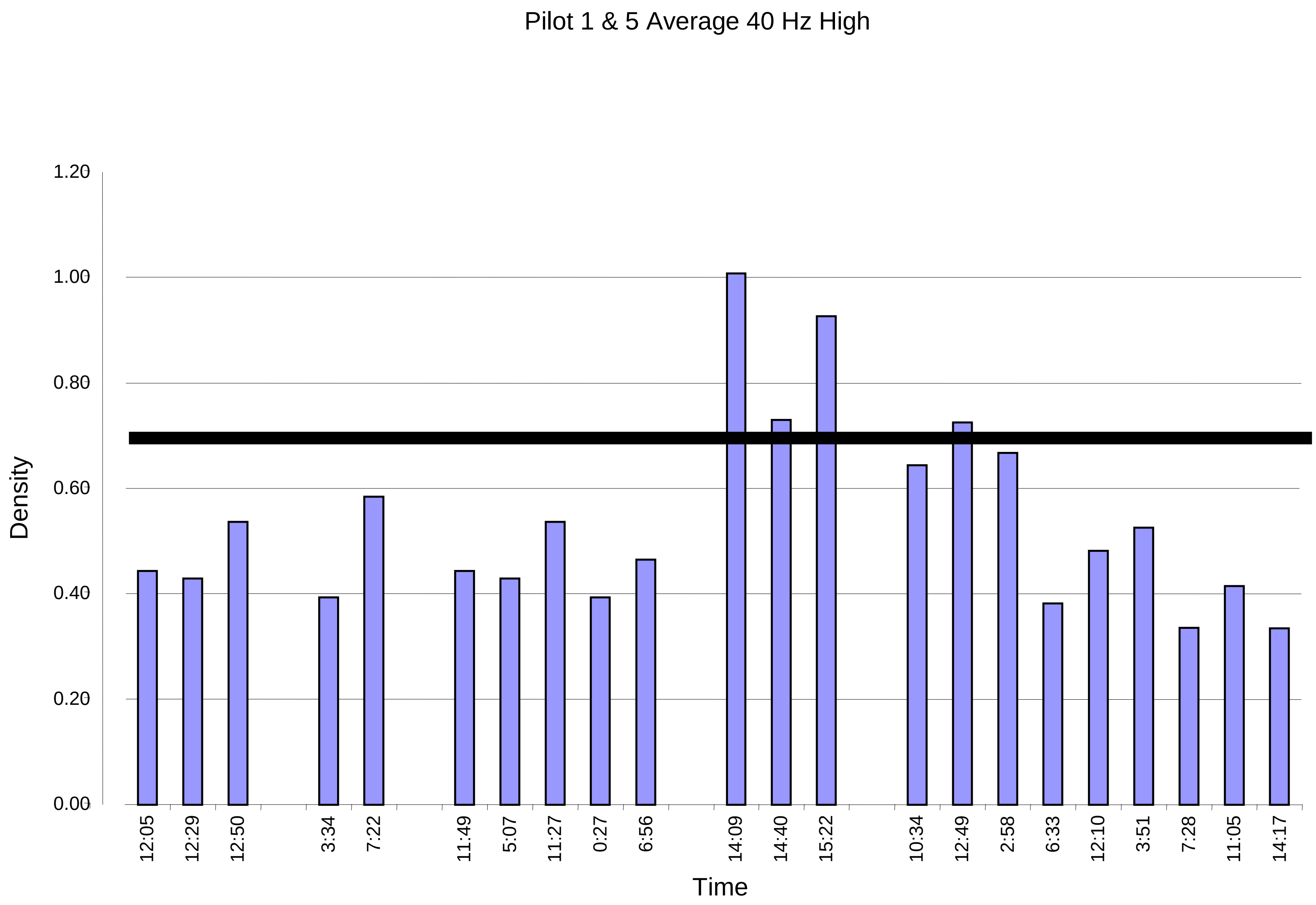

Pilot 9 MT Not Normalized
Score
1600
1400
1200
1000
800
600
400
200
0
14:11
14:35
15:00
21:48
0:29
3:19
4:14
7:26
10:14
13:04
0:24
2:56
5:04
6:41
9:28
12:15
14:52
14:29
16:12
18:32
12:45
14:25
15:45
Time

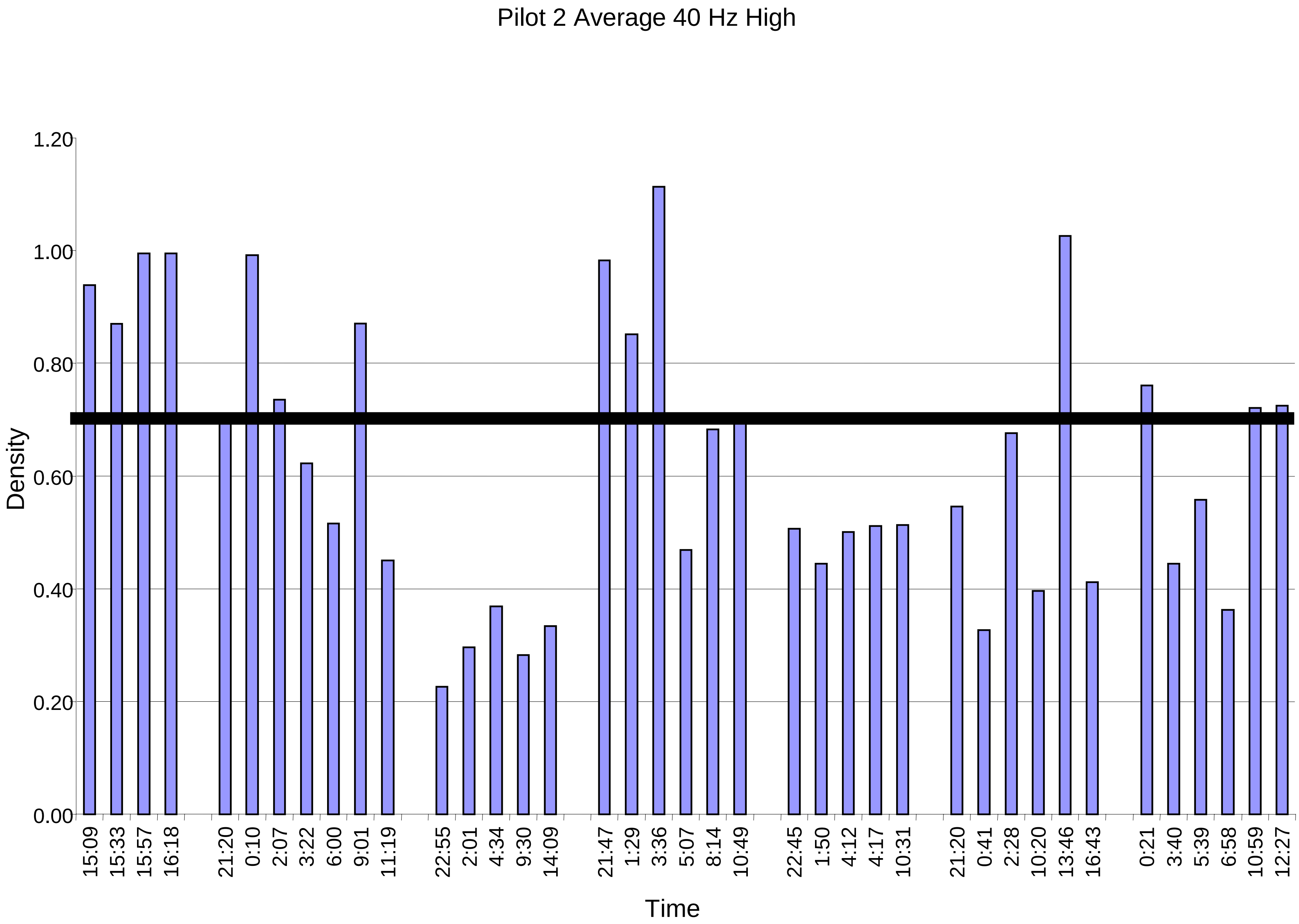
Pilot 10 MT Not Normalized

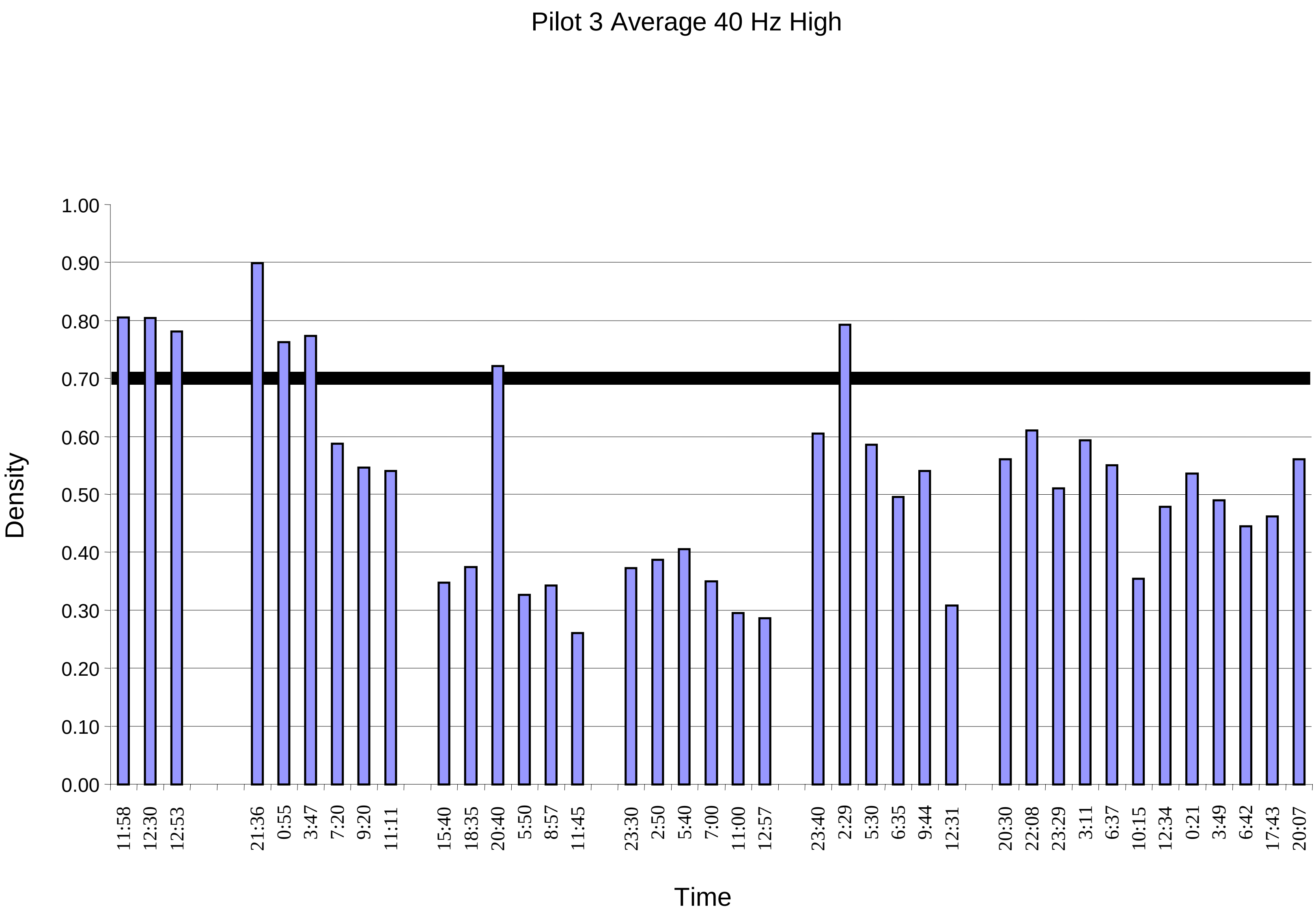


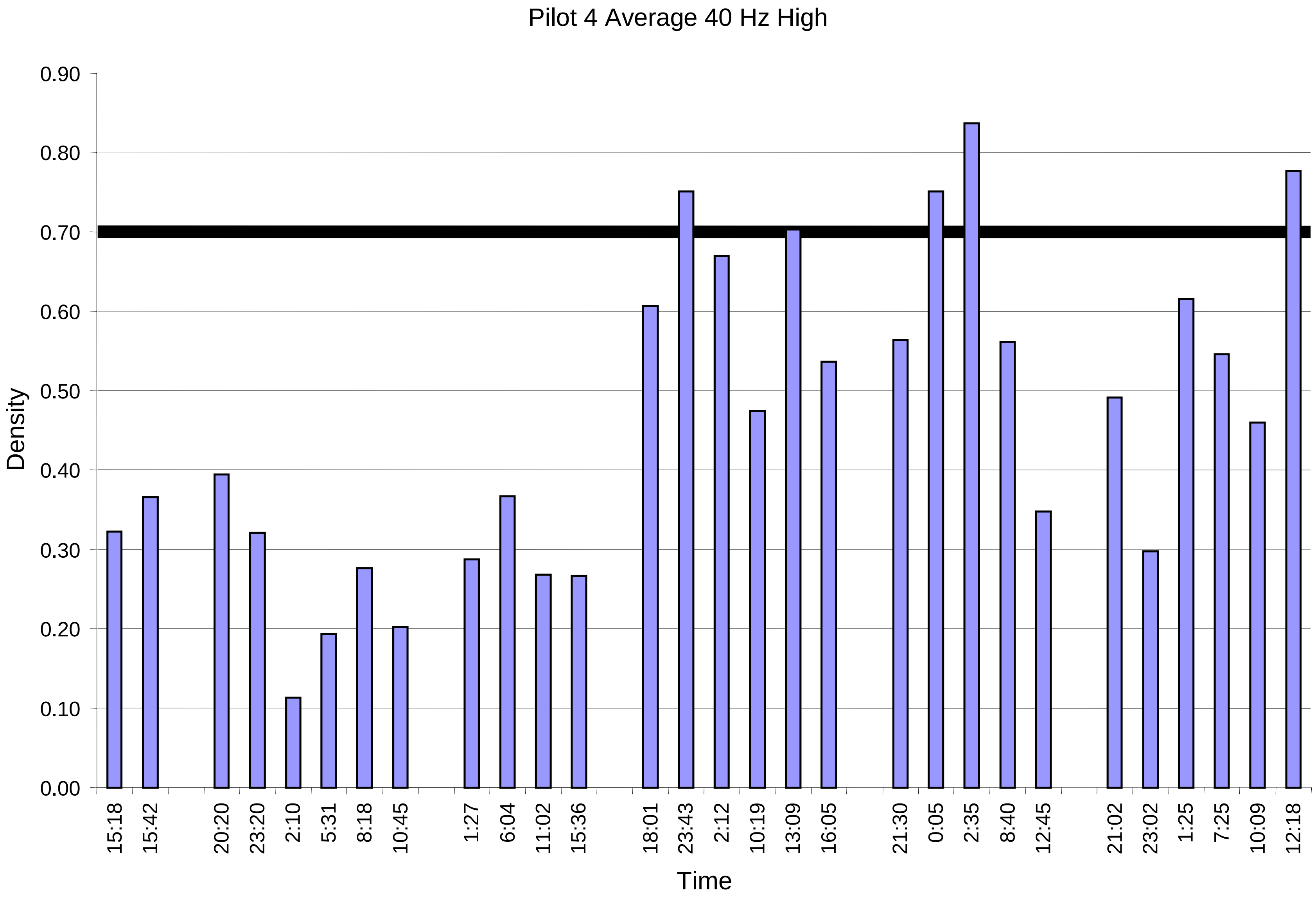
Appendix D

Averaged 40 Hz Not Normalized

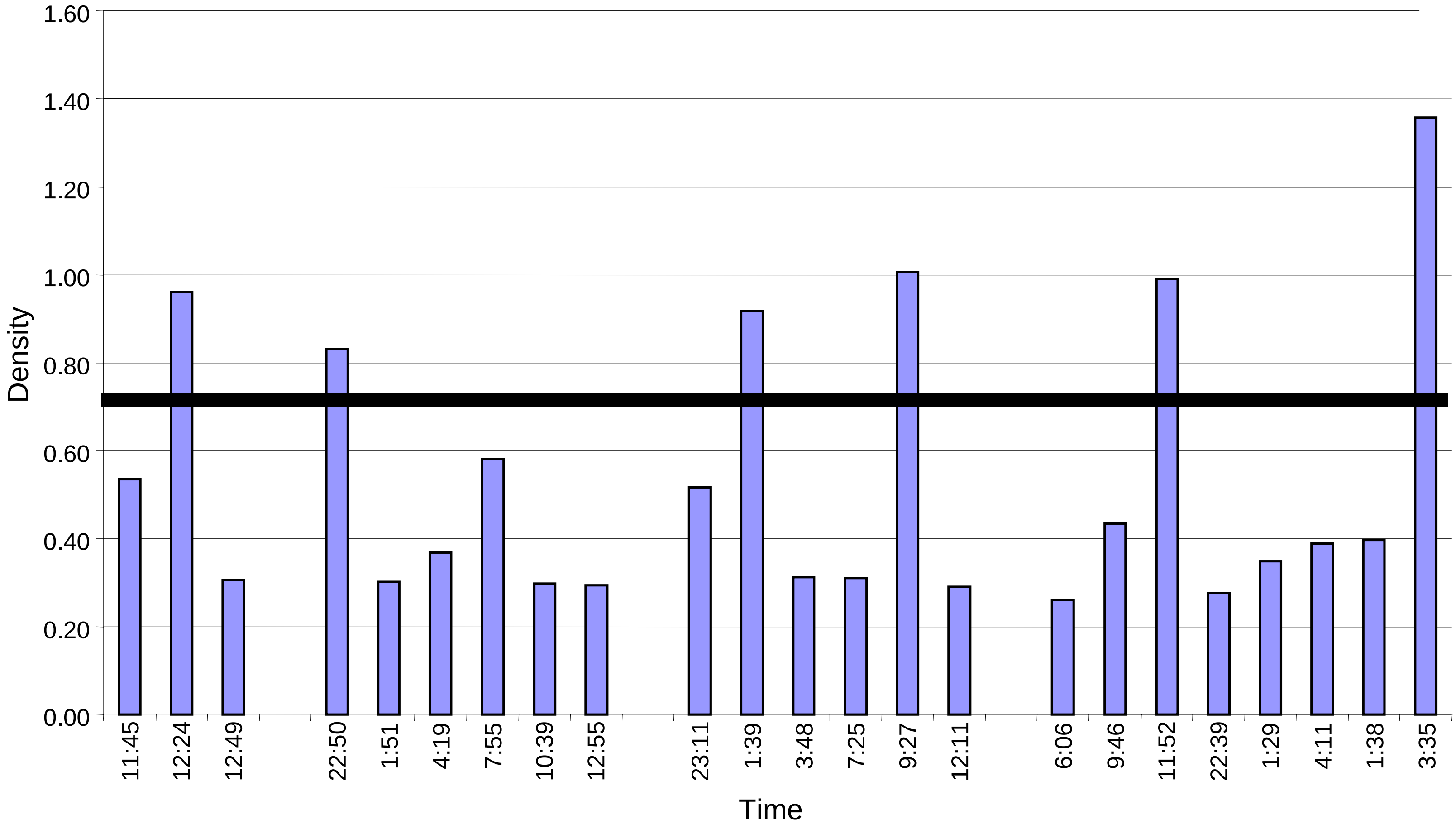

Pilot 1 & 5 Average 40 Hz High
Density
1.20
1.00
0.80
0.60
0.40
0.20
0.00
12:05
12:29
12:50
3:34
7:22
11:49
5:07
11:27
0:27
6:56
14:09
14:40
15:22
10:34
12:49
2:58
6:33
12:10
3:51
7:28
11:05
14:17
Time

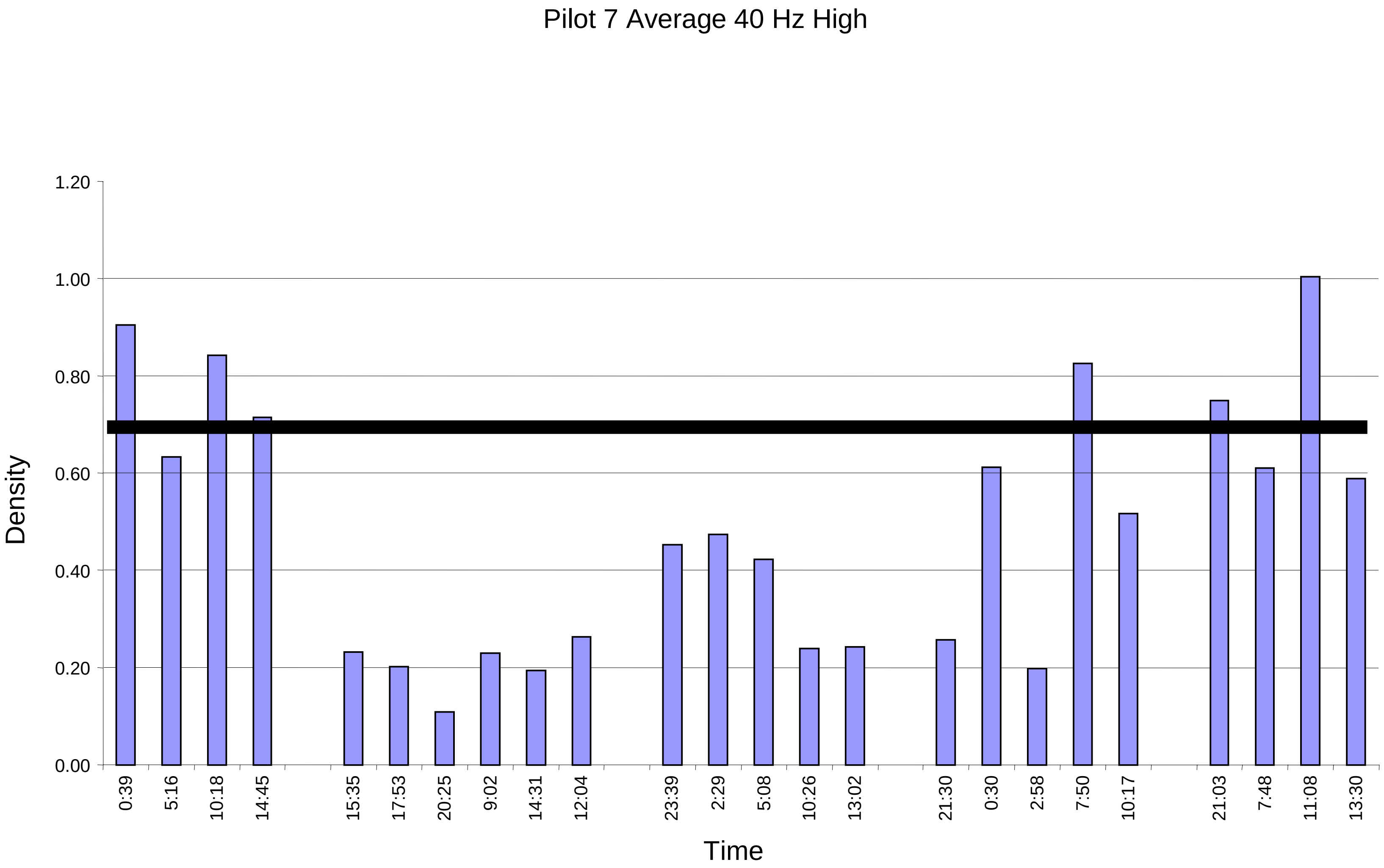

Pilot 2 Average 40 Hz High
Density
1.20
1.00
0.80
0.60
0.40
0.20
0.00
15:09
15:33
15:57
16:18
21:20
0:10
2:07
3:22
6:00
9:01
11:19
22:55
2:01
4:34
9:30
14:09
21:47
1:29
3:36
5:07
8:14
10:49
22:45
1:50
4:12
4:17
10:31
21:20
0:41
2:28
10:20
13:46
16:43
0:21
3:40
5:39
6:58
10:59
12:27
Time

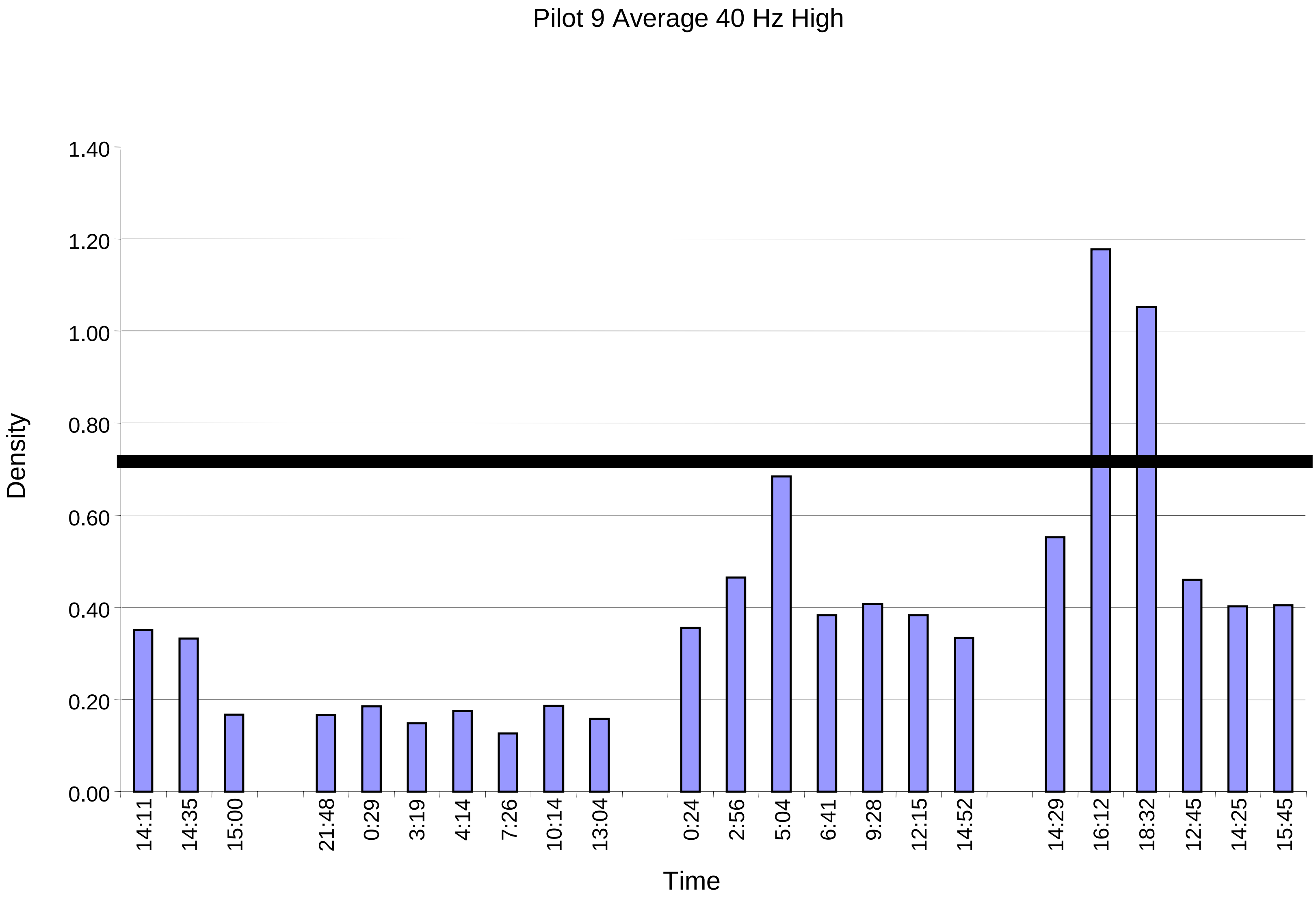

Pilot 3 Average 40 Hz High
Density
Time
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
11:58
12:30
12:53
21:36
0:55
3:47
7:20
9:20
11:11
15:40
18:35
20:40
5:50
8:57
11:45
23:30
2:50
5:40
7:00
11:00
12:57
23:40
2:29
5:30
6:35
9:44
12:31
20:30
22:08
23:29
3:11
6:37
10:15
12:34
0:21
3:49
6:42
17:43
20:07


Pilot 4 Average 40 Hz High
Density
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
15:18
15:42
20:20
23:20
2:10
5:31
8:18
10:45
1:27
6:04
11:02
15:36
18:01
23:43
2:12
10:19
13:09
16:05
21:30
0:05
2:35
8:40
12:45
21:02
23:02
1:25
7:25
10:09
12:18
Time

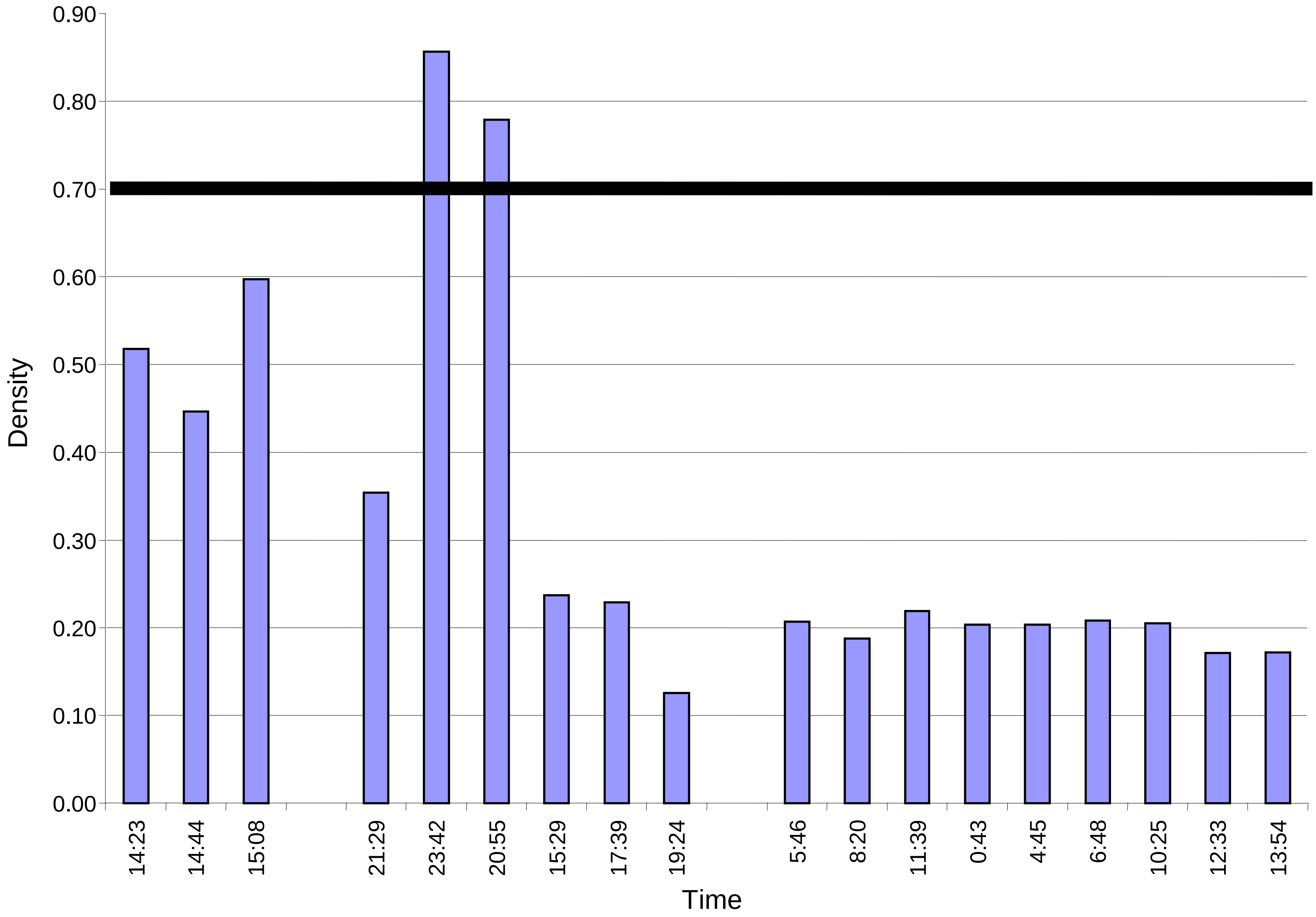
Pilot 6 Average 40 Hz High




Pilot 7 Average 40 Hz High
Density
Time
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0:39
5:16
10:18
14:45
15:35
17:53
20:25
9:02
14:31
12:04
23:39
2:29
5:08
10:26
13:02
21:30
0:30
2:58
7:50
10:17
21:03
7:48
11:08
13:30

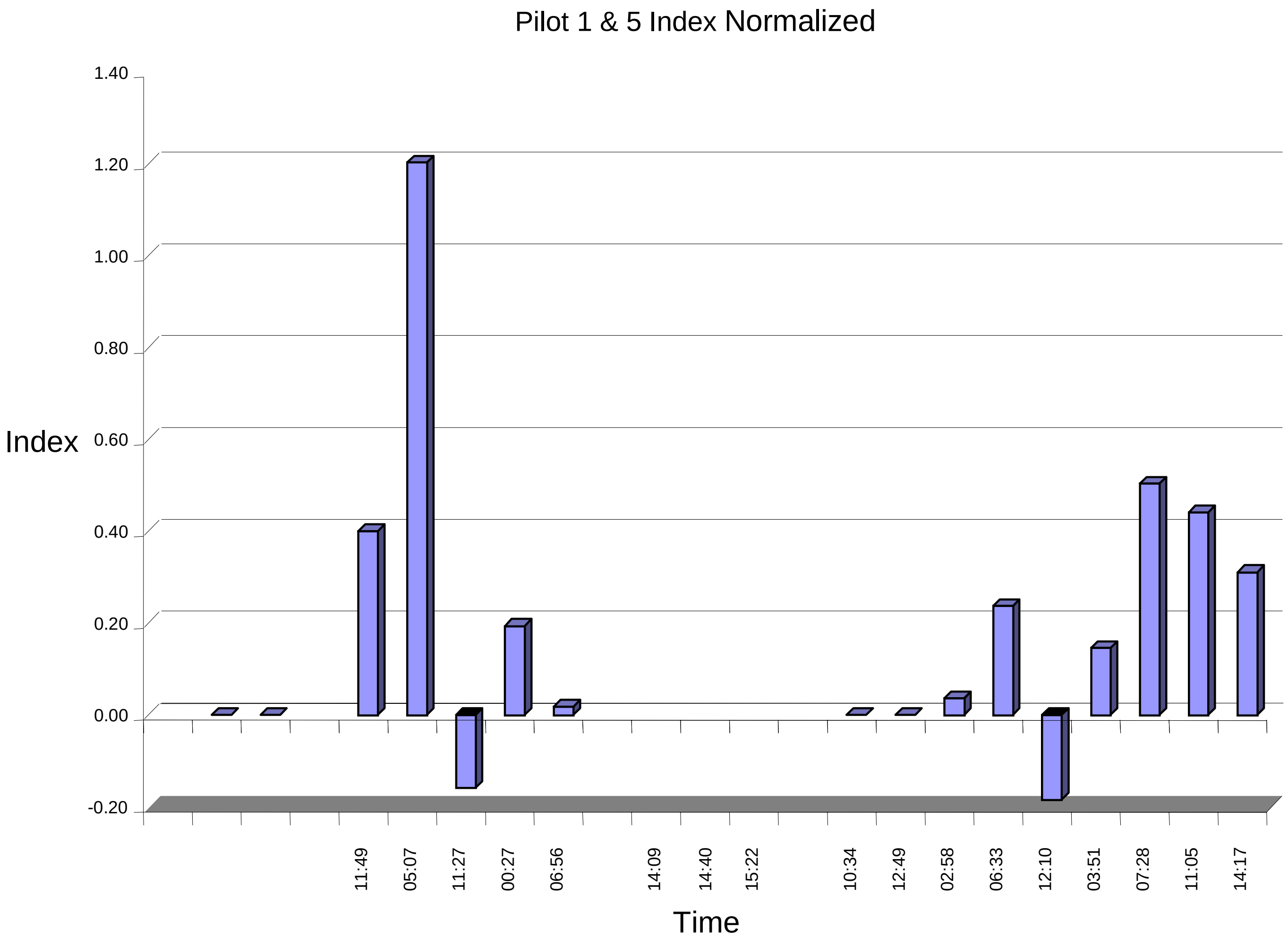

Pilot 9 Average 40 Hz High
Density
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
14:11
14:35
15:00
21:48
0:29
3:19
4:14
7:26
10:14
13:04
0:24
2:56
5:04
6:41
9:28
12:15
14:52
14:29
16:12
18:32
12:45
14:25
15:45
Time

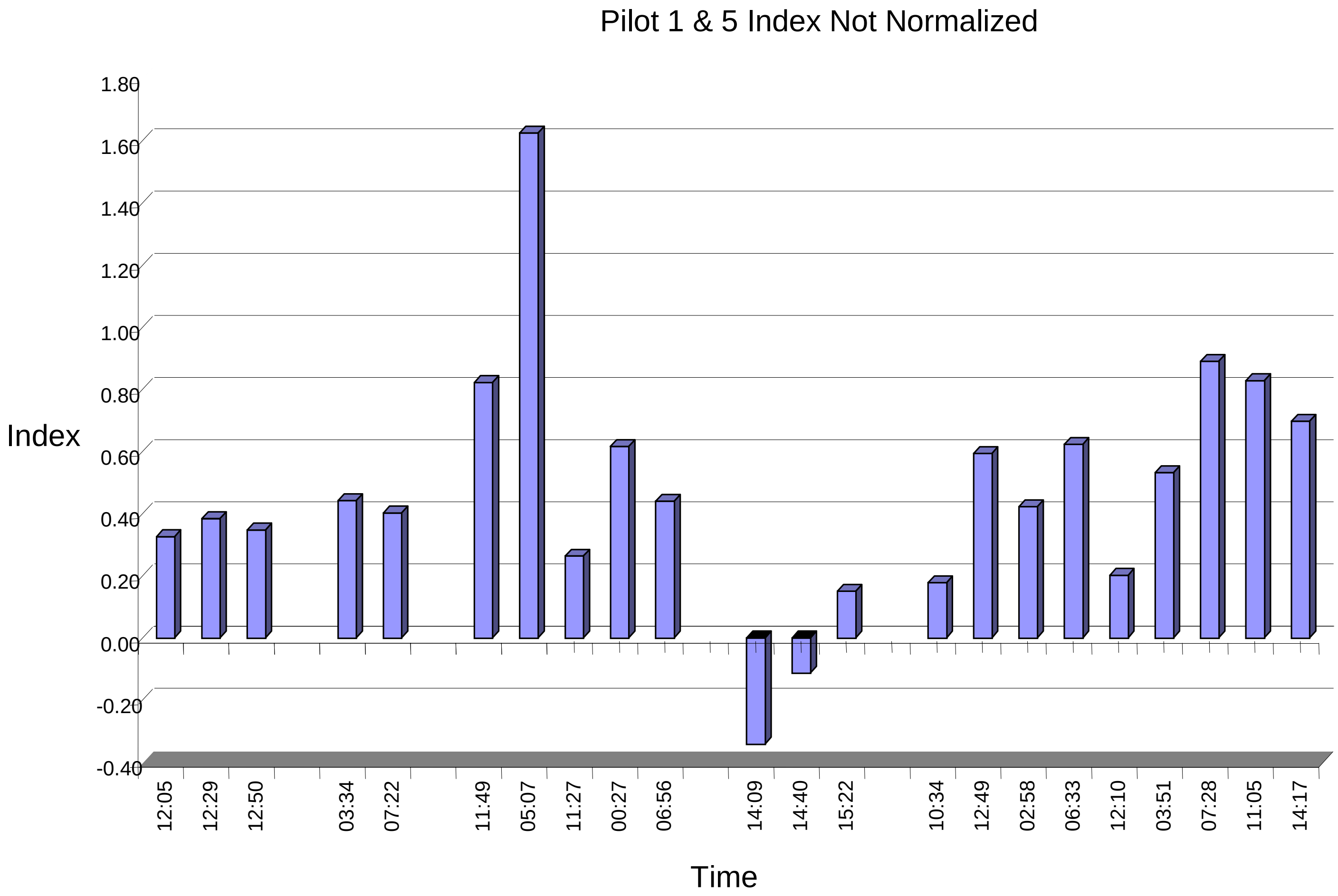
Pilot 10 Average 40 Hz High

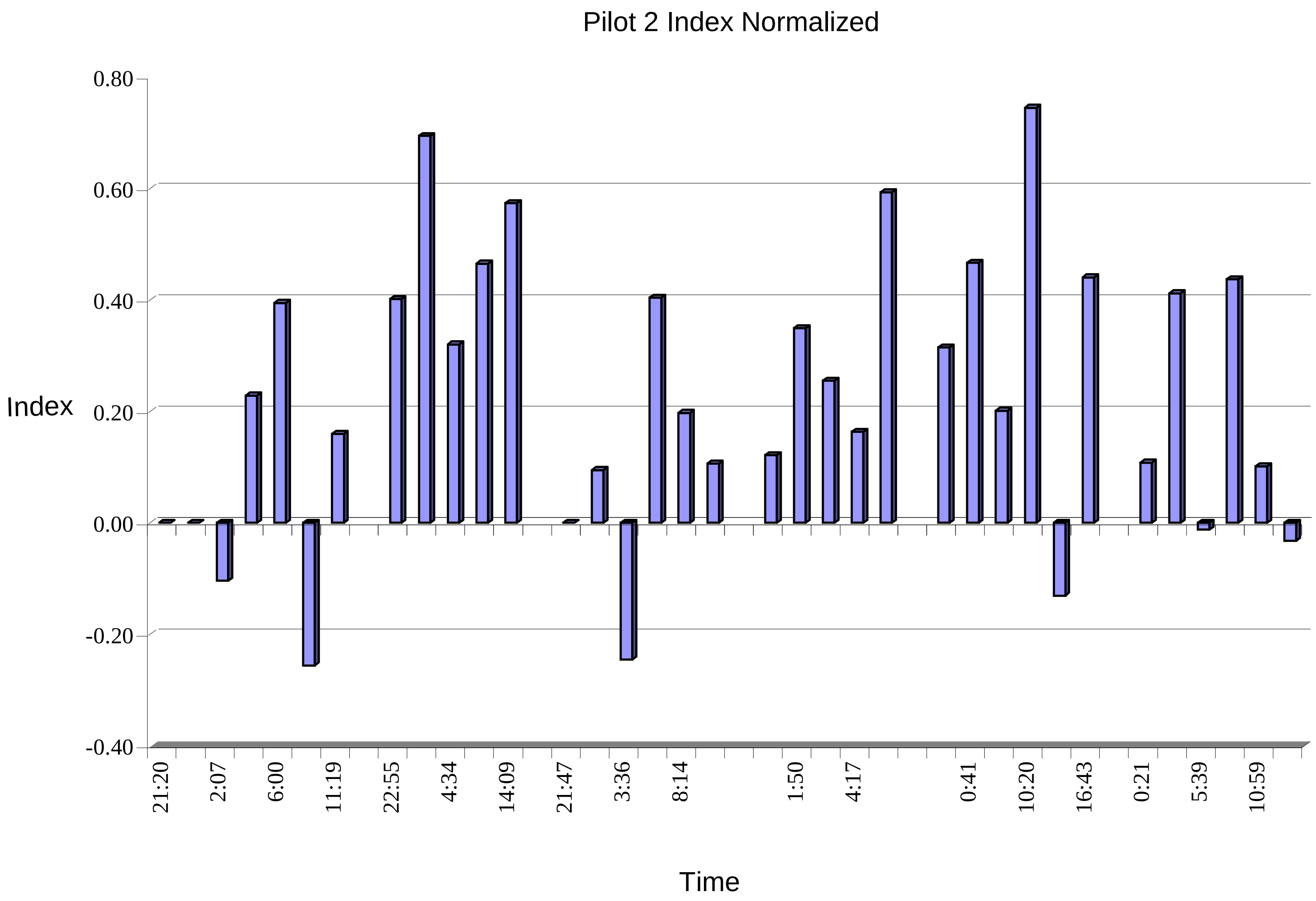


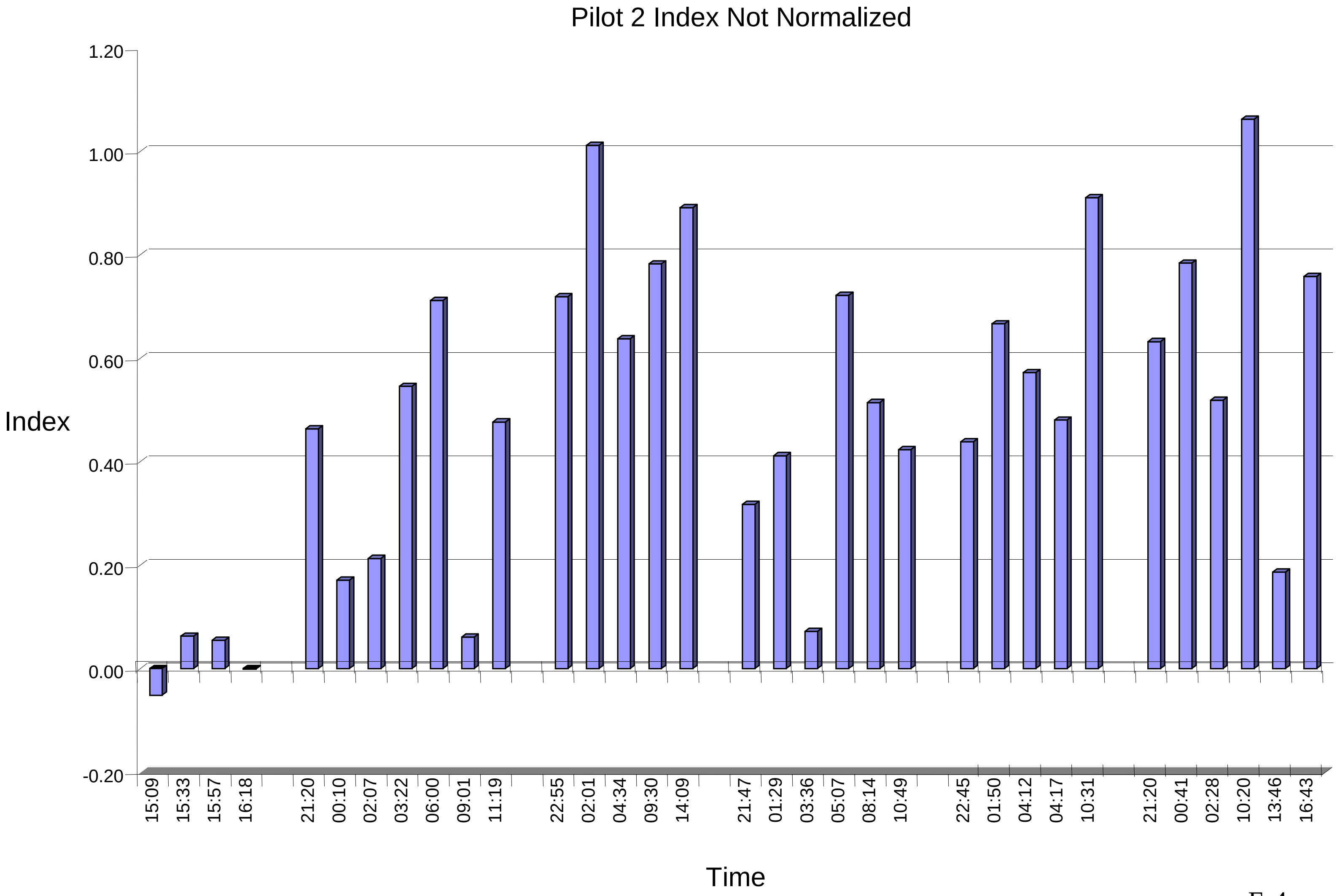
Appendix E

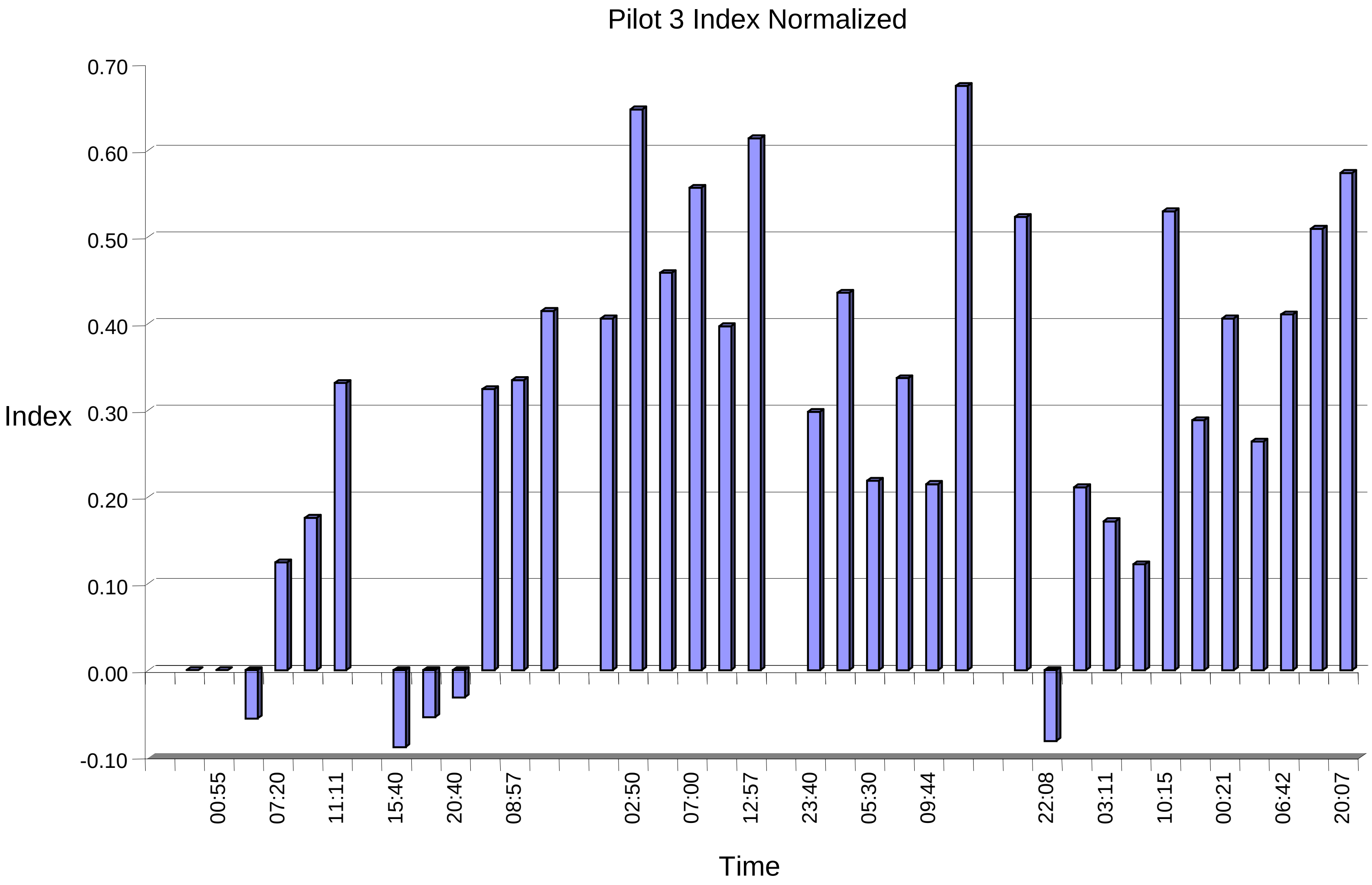
Pilot Indexes Normalized and Not Normalized

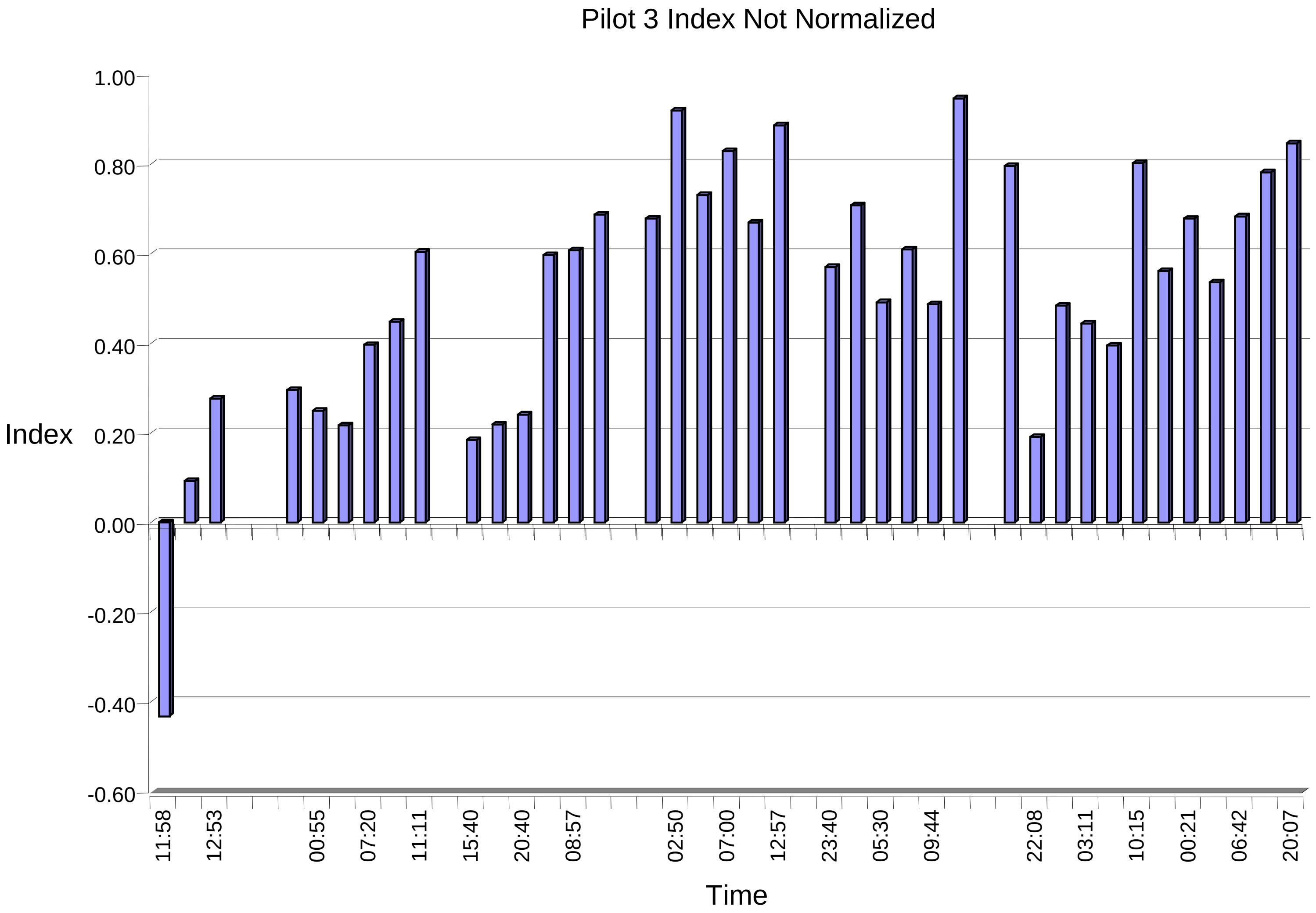

Pilot 1 & 5 Index Normalized
Index
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
11:49
05:07
11:27
00:27
06:56
14:09
14:40
15:22
10:34
12:49
02:58
06:33
12:10
03:51
07:28
11:05
14:17
Time

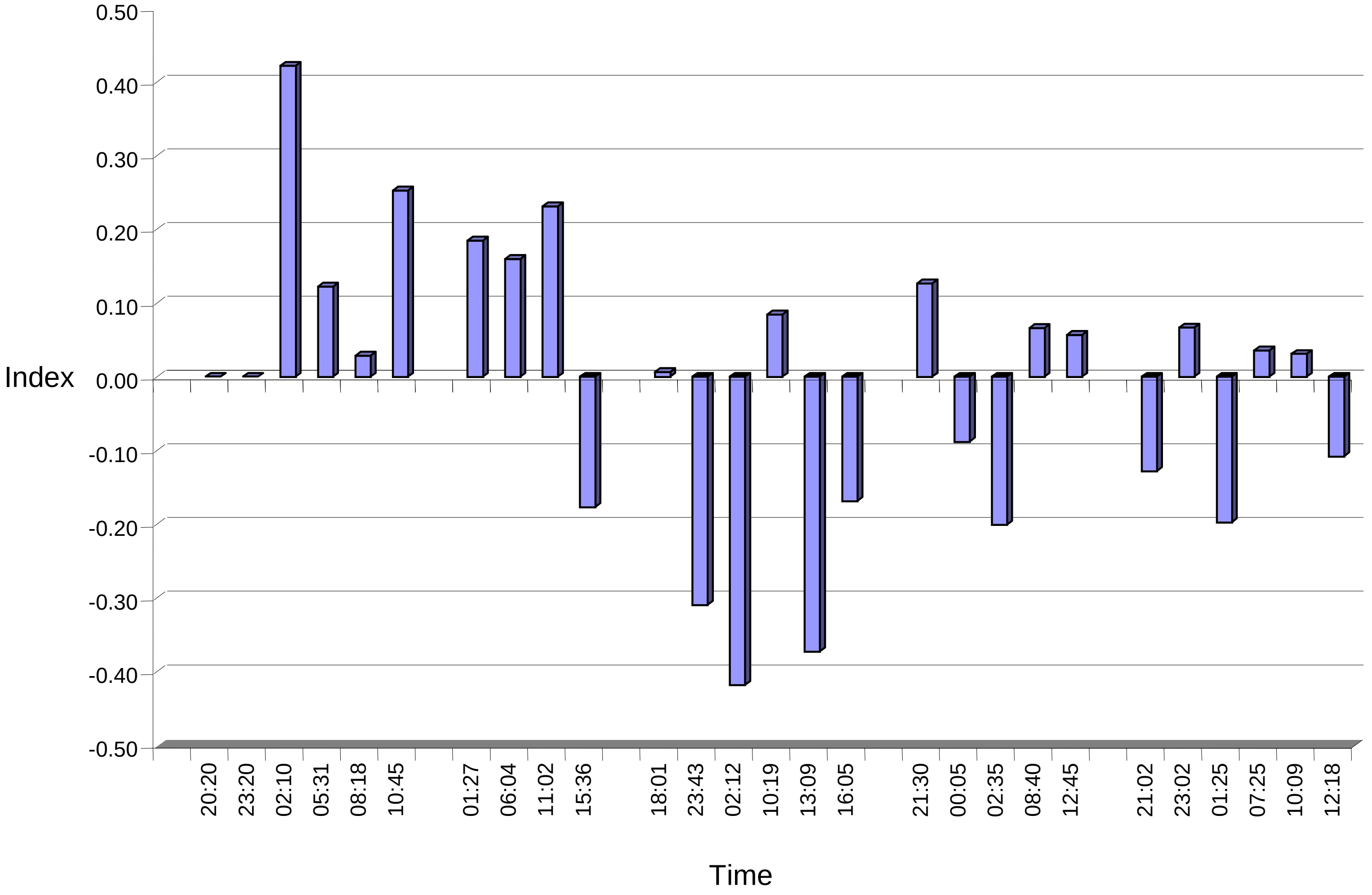

Pilot 1 & 5 Index Not Normalized
Index
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
12:05
12:29
12:50
03:34
07:22
11:49
05:07
11:27
00:27
06:56
14:09
14:40
15:22
10:34
12:49
02:58
06:33
12:10
03:51
07:28
11:05
14:17
Time


Pilot 2 Index Normalized
Index
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
21:20
2:07
6:00
11:19
22:55
4:34
14:09
21:47
3:36
8:14
1:50
4:17
0:41
10:20
16:43
0:21
5:39
10:59
Time

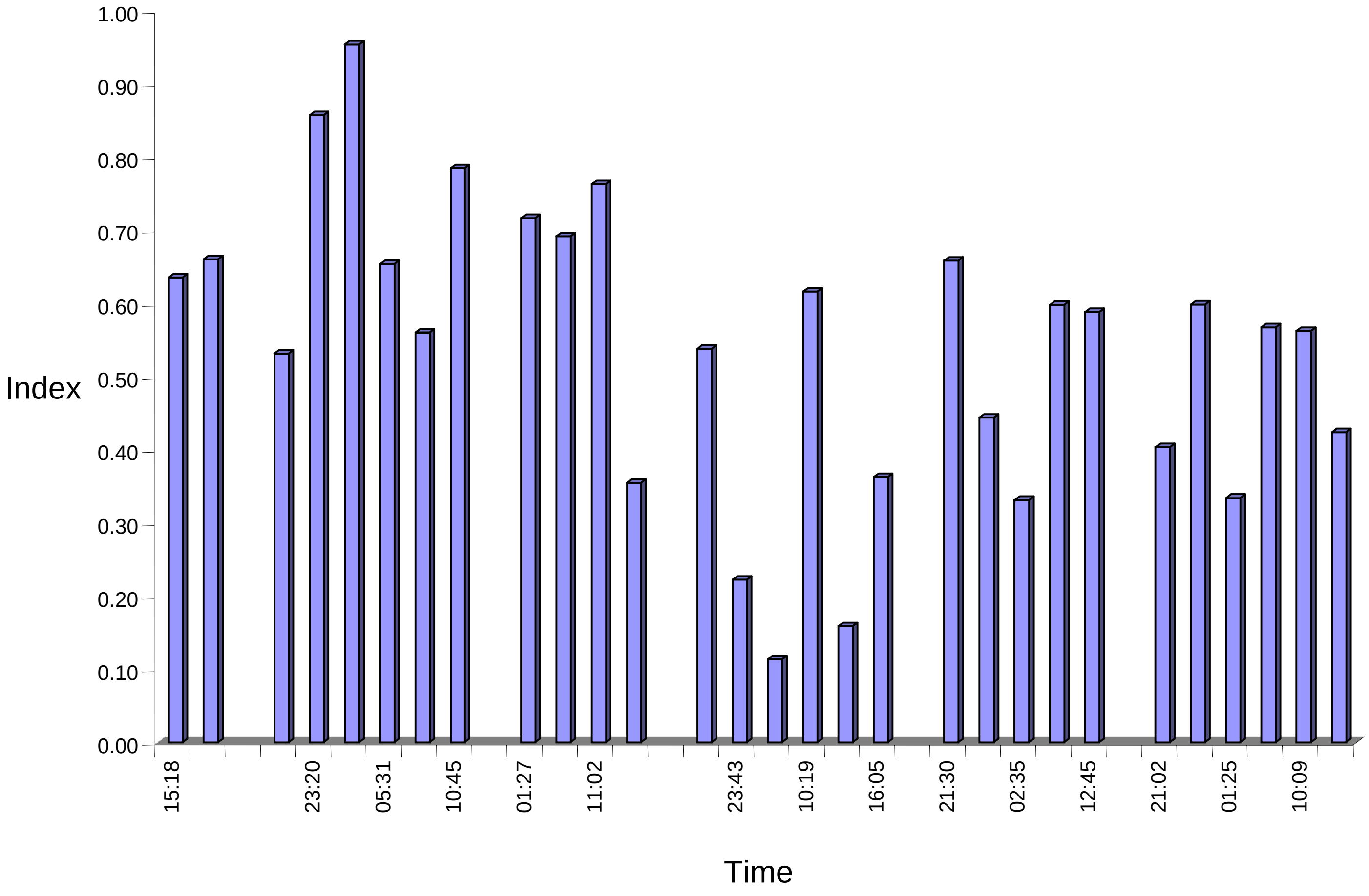

Pilot 2 Index Not Normalized
Index
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
15:09
15:33
15:57
16:18
21:20
00:10
02:07
03:22
06:00
09:01
11:19
22:55
02:01
04:34
09:30
14:09
21:47
01:29
03:36
05:07
08:14
10:49
22:45
01:50
04:12
04:17
10:31
21:20
00:41
02:28
10:20
13:46
16:43
Time

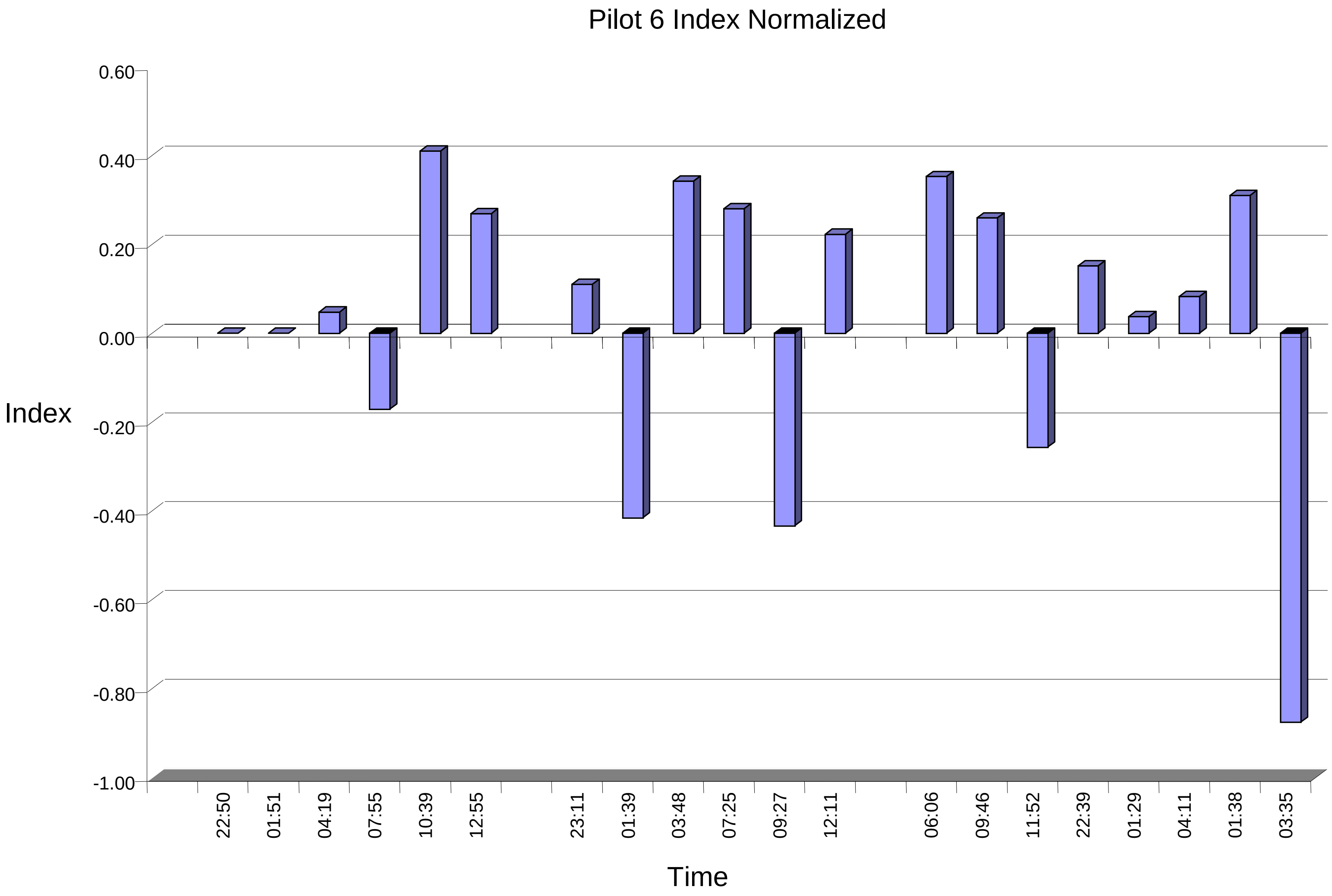

Pilot 3 Index Normalized
Index
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
00:55
07:20
11:11
15:40
20:40
08:57
02:50
07:00
12:57
23:40
05:30
09:44
22:08
03:11
10:15
00:21
06:42
20:07
Time

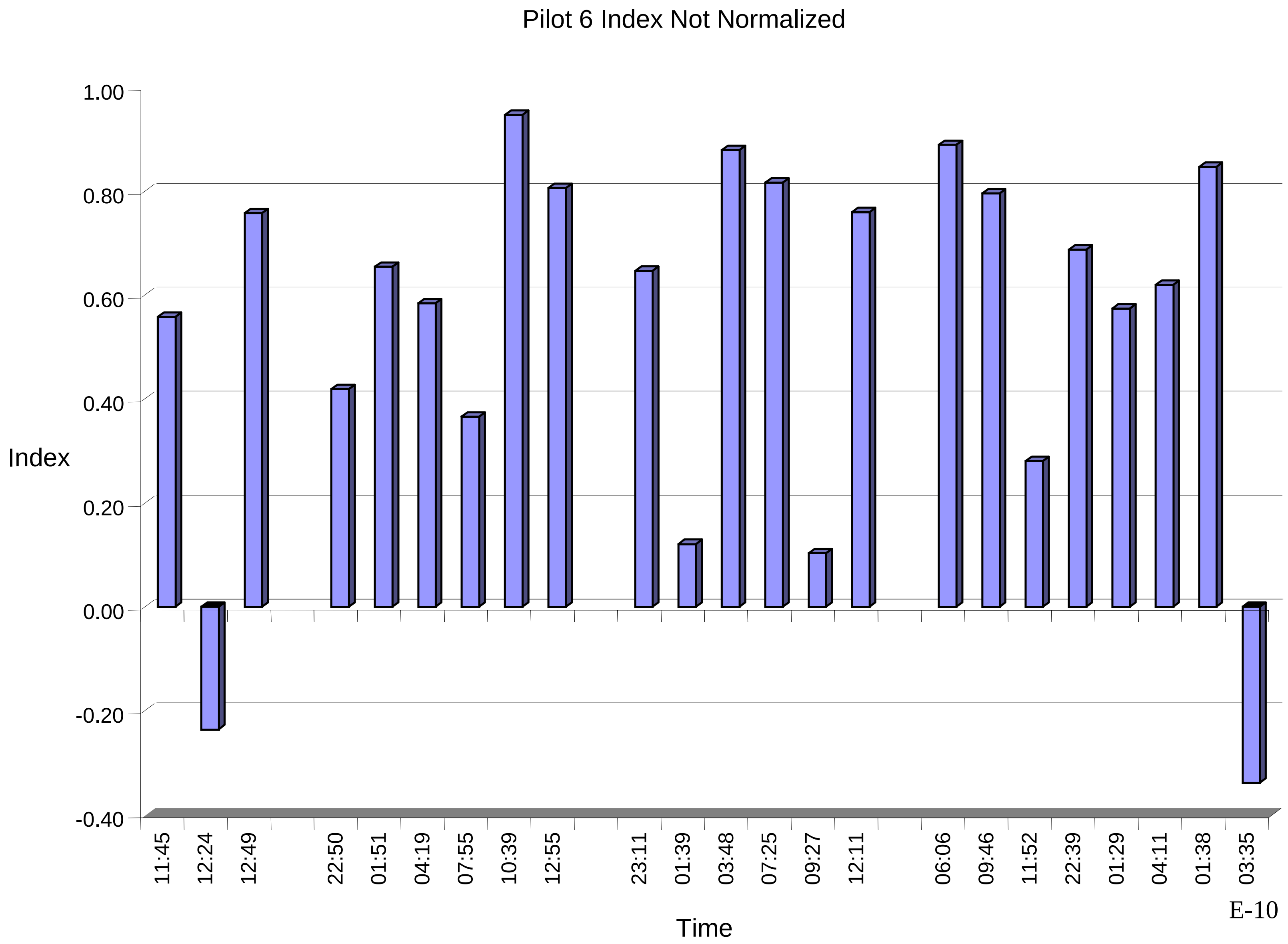

Pilot 3 Index Not Normalized
Index
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
11:58
12:53
00:55
07:20
11:11
15:40
20:40
08:57
02:50
07:00
12:57
23:40
05:30
09:44
22:08
03:11
10:15
00:21
06:42
20:07
Time

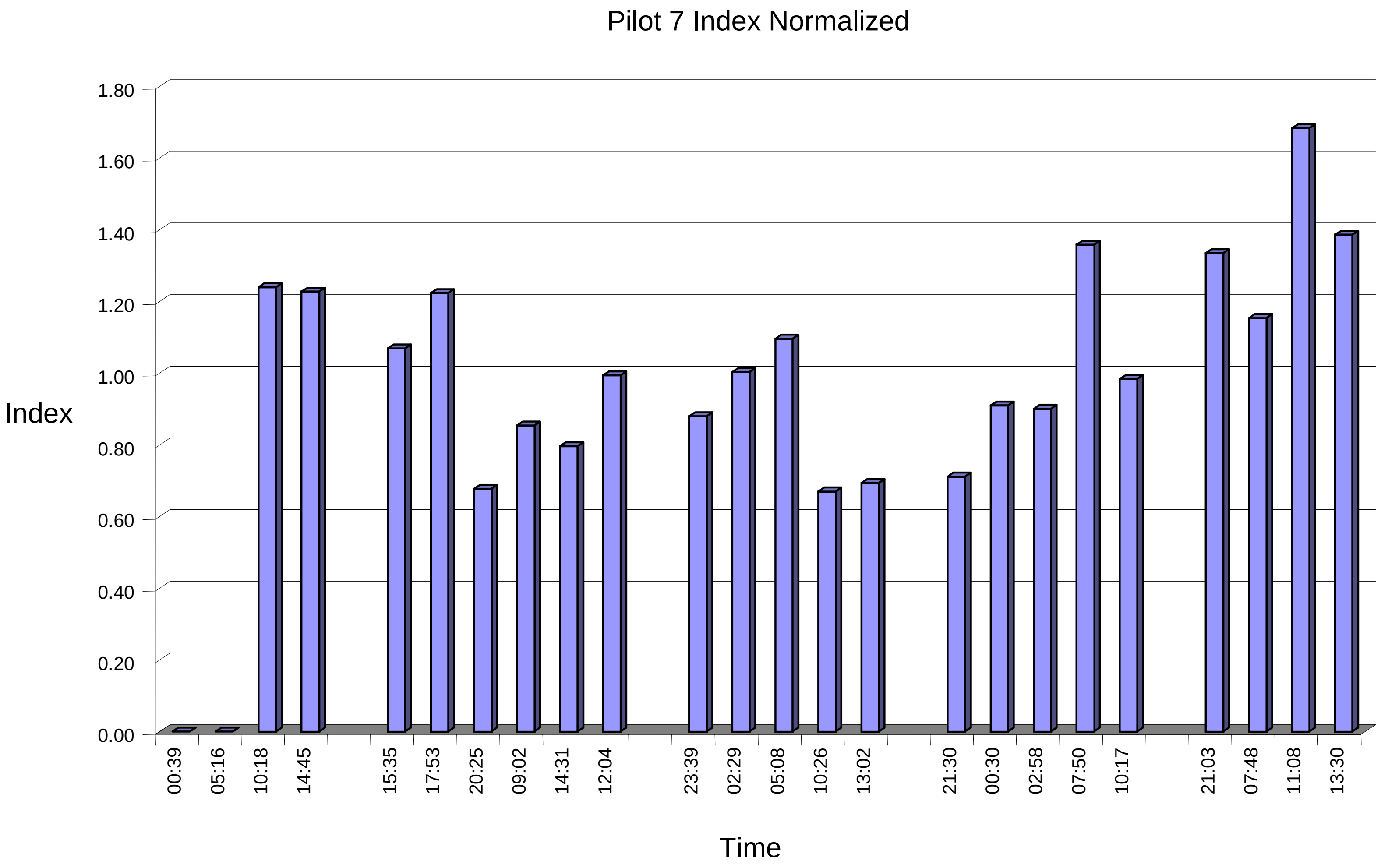

Pilot 4 Index Normalized

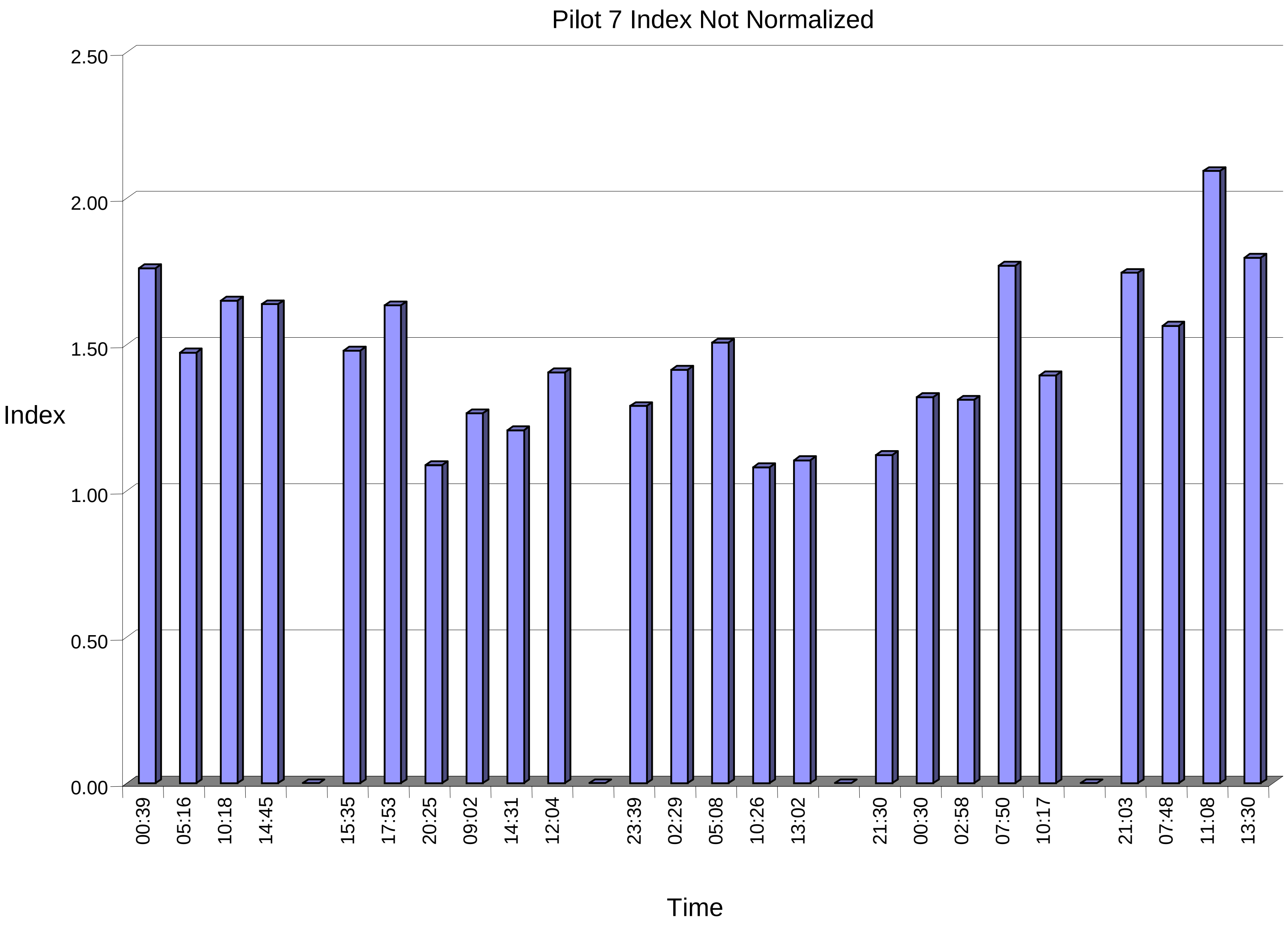
Pilot 4 Index Not Normalized

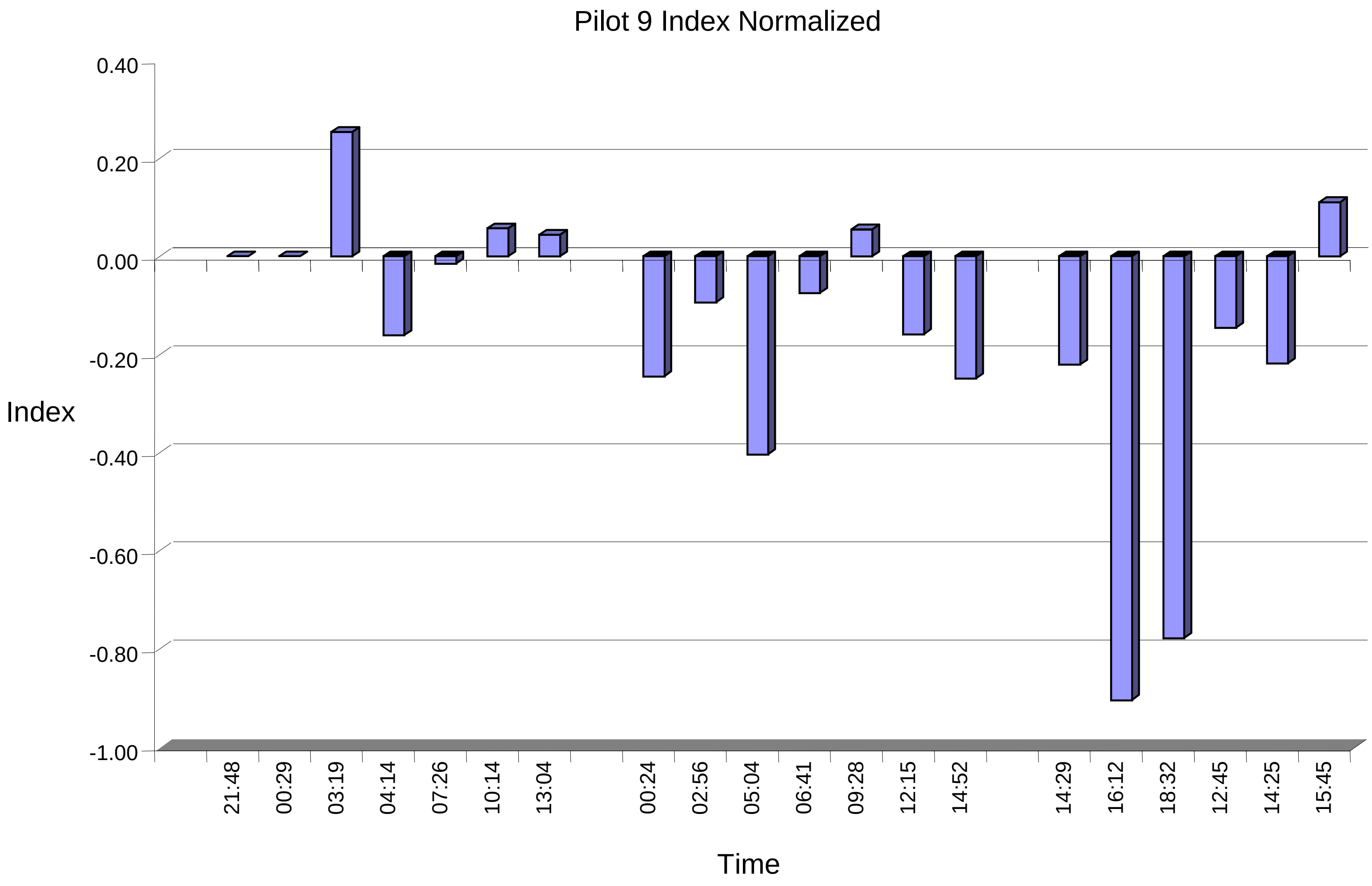


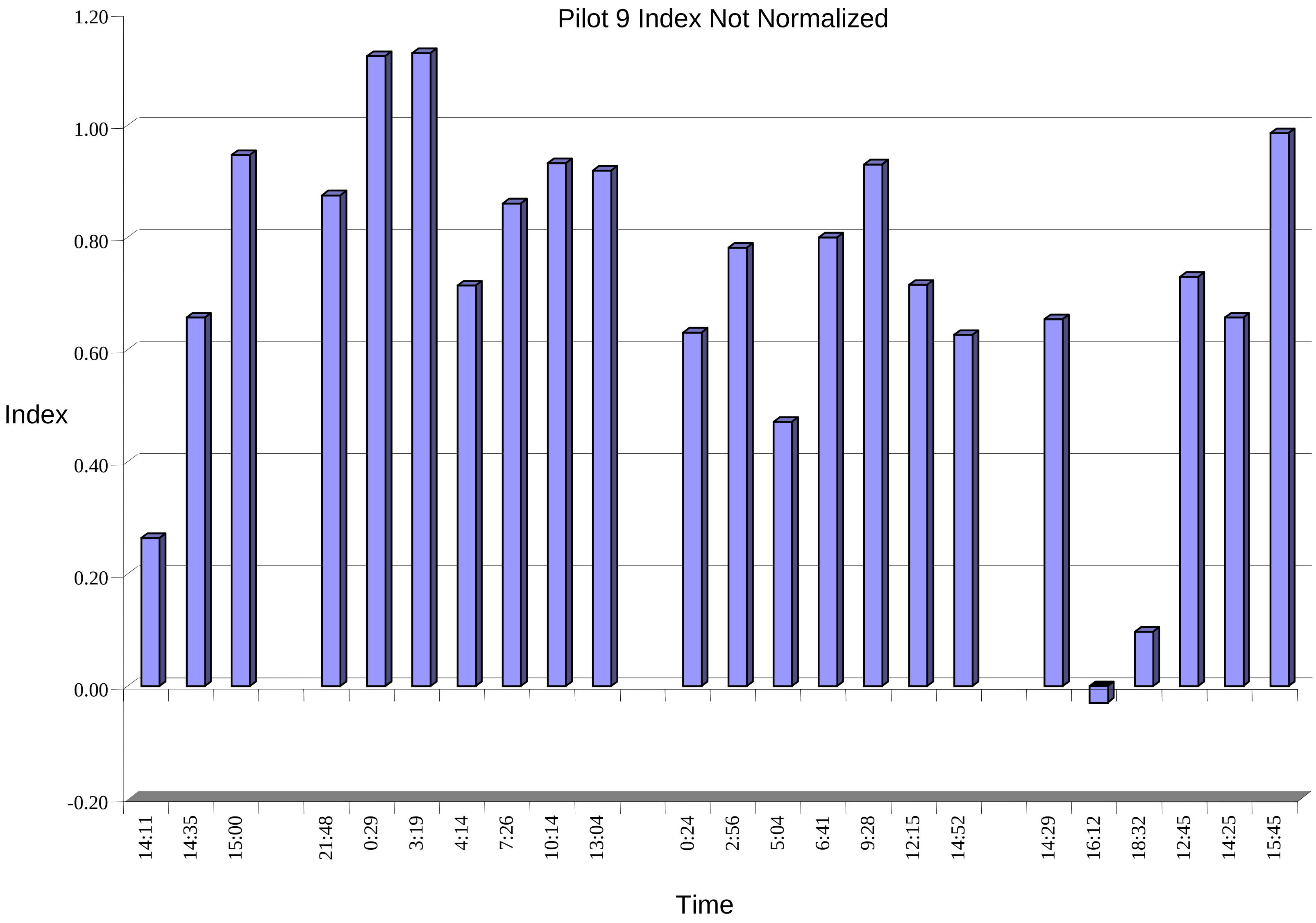

Pilot 6 Index Normalized
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
Index
22:50
01:51
04:19
07:55
10:39
12:55
23:11
01:39
03:48
07:25
09:27
12:11
06:06
09:46
11:52
22:39
01:29
04:11
01:38
03:35
Time

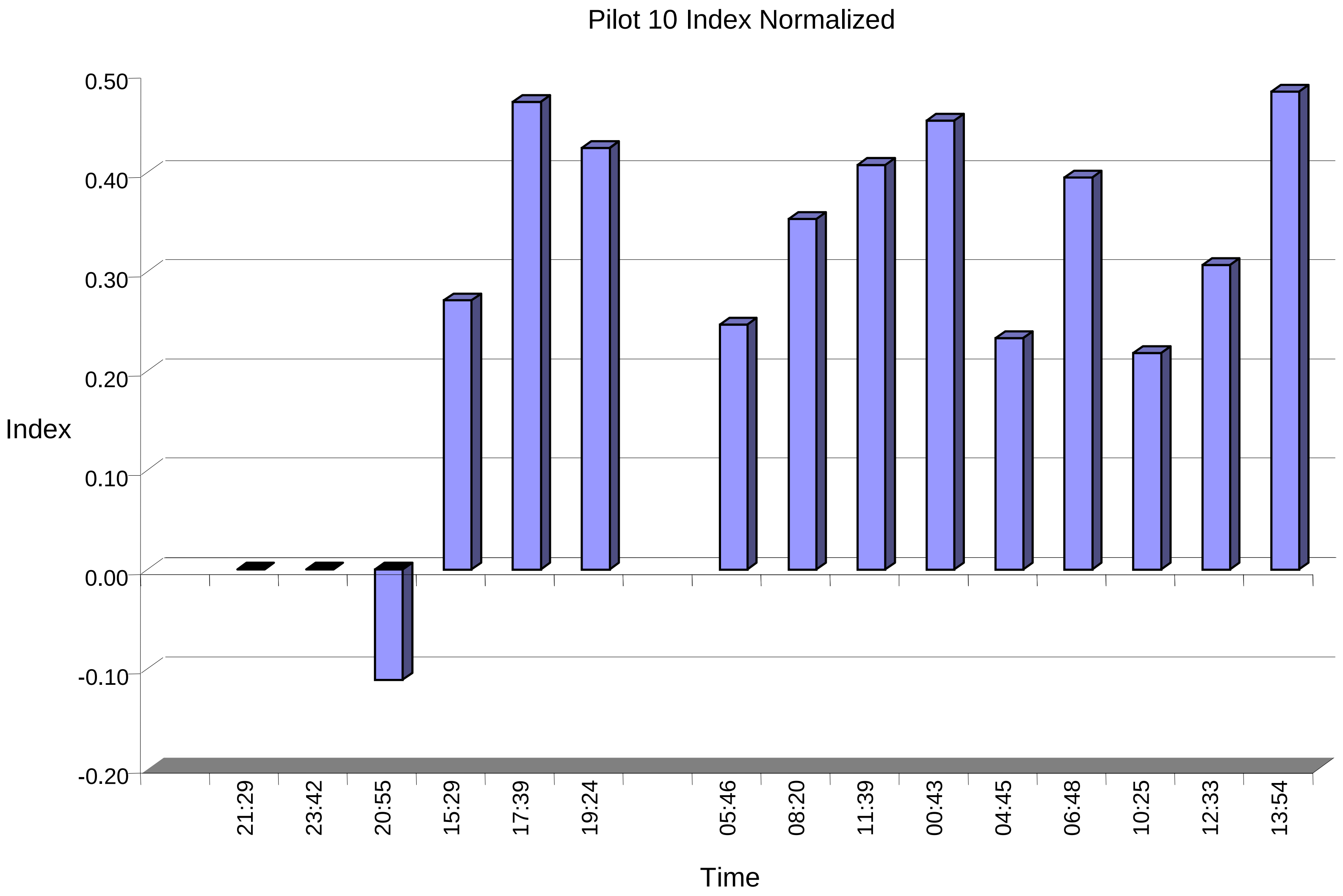

Pilot 6 Index Not Normalized
Index
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
11:45
12:24
12:49
22:50
01:51
04:19
07:55
10:39
12:55
23:11
01:39
03:48
07:25
09:27
12:11
06:06
09:46
11:52
22:39
01:29
04:11
01:38
03:35
Time

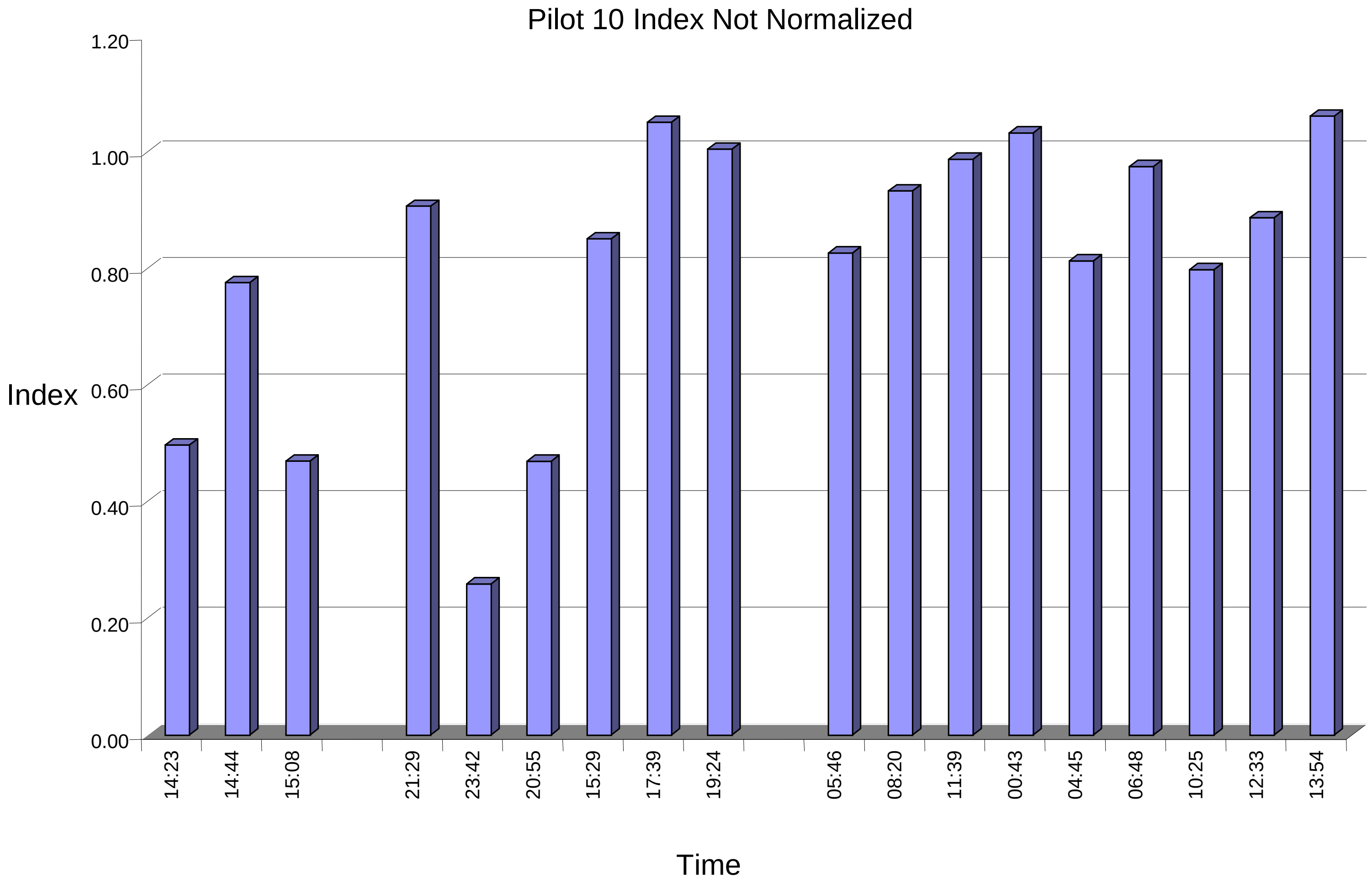

Pilot 7 Index Normalized
Index
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
00:39
05:16
10:18
14:45
15:35
17:53
20:25
09:02
14:31
12:04
23:39
02:29
05:08
10:26
13:02
21:30
00:30
02:58
07:50
10:17
21:03
07:48
11:08
13:30
Time


Pilot 7 Index Not Normalized
Index
2.50
2.00
1.50
1.00
0.50
0.00
00:39
05:16
10:18
14:45
15:35
17:53
20:25
09:02
14:31
12:04
23:39
02:29
05:08
10:26
13:02
21:30
00:30
02:58
07:50
10:17
21:03
07:48
11:08
13:30
Time


Pilot 9 Index Normalized
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
Index
21:48
00:29
03:19
04:14
07:26
10:14
13:04
00:24
02:56
05:04
06:41
09:28
12:15
14:52
14:29
16:12
18:32
12:45
14:25
15:45
Time


Pilot 9 Index Not Normalized
Index
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
14:11
14:35
15:00
21:48
0:29
3:19
4:14
7:26
10:14
13:04
0:24
2:56
5:04
6:41
9:28
12:15
14:52
14:29
16:12
18:32
12:45
14:25
15:45
Time


Pilot 10 Index Normalized
Index
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
21:29
23:42
20:55
15:29
17:39
19:24
05:46
08:20
11:39
00:43
04:45
06:48
10:25
12:33
13:54
Time


Pilot 10 Index Not Normalized
Index
1.20
1.00
0.80
0.60
0.40
0.20
0.00
14:23
14:44
15:08
21:29
23:42
20:55
15:29
17:39
19:24
05:46
08:20
11:39
00:43
04:45
06:48
10:25
12:33
13:54
Time

Appendix F

Description of Experiment

Description Of Experiment

This experiment is a joint effort by Transport Canada and DND to establish whether it is feasible to give pilots an objective index of their level of fatigue during flight. We are testing two methods and hope to combine them as a single index: multitasking and EEG. The multitasking is a computer display that requires visuo-motor co-ordination and other types of information processing. The tasks are described in the Instructions for Multitasking that are attached.

The second method, EEG, is to get an index of the efficiency of brain function during flight and particularly during the period when you will be doing the multitasking. We will be analysing the EEG in the laboratory and combining those measures with the multitasking scores. We will be asking you to complete the multitasking approximately every three hours when it does not interfere with your duties. The multitasking is configured on a laptop computer that is powered by batteries and may be moved to any convenient location. The multitasking will take approximately 15 minutes to complete. When you are using the multitasking program we wish to record EEG from two electrodes placed on your scalp and one ear. The scalp electrodes measure how alert you are during the multitasking – they are applied by pressing them into a small glob of conductive paste that is pressed into the hair and makes contact with the scalp. The paste is water-soluble and can be removed easily with a wet cloth.

All data is completely confidential and automatically coded so that the data cannot be associated with any individual. However, if you want us to send you a summary of your data, both multitasking and EEG, and our initial interpretations, please indicate that on the consent form and we will be happy to do so. After the data has been sent to you, if you wish us to do so the data will be permanently de-identified.

In addition you will be asked to fill out a Sleep Log at your convenience but before the end of the flight – the log is attached.

If at any time when you are engaged in testing you wish to terminate or suspend the procedure simply let the experimenter know and he or she will remove the electrodes and close the program.

If your duties require it you may remove the electrodes yourself at any time by simply pulling them out of the paste. You may simply put aside the laptop.

On behalf of Canada 3000 and Transport Canada we would like to thank you for participating in this experiment, which we believe may lead to a method for pilots to objectively assess their own levels of fatigue during difficult flight schedules.

Appendix G

Participant's Instructions for the Use of Multitasking

Participant's Instructions for the Use of Multitasking

General Description.
When the program is running you will see four separate displays on the screen that represent four different tasks that must be performed simultaneously. These tasks resemble flying an aircraft through a simulated airspace to specific targets or "waypoints" as described below.

TRACKING TASK:
The upper left display (referred to hereafter as the "Tracking Task") represents an aircraft control panel in which a small white box shows the action of the aircraft control column. This can be controlled at any time by motions that bank the aircraft to the left or right, increasing or decreasing the rate of turn in relation to the aircraft's heading in degrees per second. Up and down pitches the aircraft up or down, increasing or decreasing the rate of change of altitude in feet per minute. These values are displayed on the panel along with the current aircraft heading and altitude, which will change accordingly. In addition, there are flight director "cursors" (shown in orange on the same display), which help guide the change of aircraft climb/descend rate and heading based on what has been entered into the "flight computer". Thus, these cursors move accordingly if the current target values are changed by using the F1 and F2 keys and typing in new values and will indicate the necessary flying pattern needed to achieve the new heading and/or altitude. When the program starts the aircraft will already be on the entered heading (0.0 degrees) and altitude (5,000 ft). The object of this task is to maintain the aircraft on the current target heading and altitude that is entered into the flight computer, i.e., to bring the orange cursors into the centre of the screen and maintain them in this position. However, the "target heading" and the "target altitude" values should be entered into the computer at any time, and will be dictated by the Waypoint Task described below.

WAYPOINT TASK:
The upper right display (referred to hereafter as the "Waypoint Task") shows a map of the ground viewed from the aircraft. Straight up on the display represents the "front" of the aircraft (i.e., the current direction of the aircraft). You will see a number of small triangles that represent waypoints, one of which will be solid green in colour, and which represents the currently active or "target" Waypoint. As soon as the correct heading of the target relative to your current position can be determined this value should be entered into the flight computer as the "target heading" (see “Tracking Task"). If the target Waypoint is not visible, the range of view of the "map" can be incrementally increased or decreased by a factor of 2 using the Zoom in and Zoom out keys (F8 and F9) as shown until it is found. Similarly, the map can be zoomed in for a more detailed view of the target Waypoint once it is in close range of the aircraft. The object of this task is to fly towards the "target Waypoint" as efficiently as possible until the waypoint intersects the aircraft. Successful "capture" of the Waypoint is achieved if the centre of the triangle passes through the small circle in the centre of the screen.

IT IS IMPORTANT TO TRY TO MINIMIZE THE AMOUNT OF TIME THAT THE TARGET HEADING IS DIFFERENT FROM THAT NEEDED TO INTERCEPT THE WAYPOINT.

Your score is reduced for the amount of time spent flying towards the target without changing the target heading to be as close to the necessary heading as possible. Once a Waypoint is intercepted, it will flash briefly and a new triangle will become the target.

A second task in this display is the instruction to change the target altitude to a new altitude (using the F1 button as described in the "Tracking Task"). This will occur periodically and will consist of the new target altitude being presented for 5 seconds at the upper left corner of the map accompanied by a short beeping sound. It is important to note these values immediately – once the display disappears from the screen it cannot be retrieved. You will also be scored on the amount of time the target heading is set to the correct value.

INSTRUMENT TASK:

The lower right display (referred to hereafter as the "Instrument Task") shows two "artificial horizon" attitude indicators, which will reflect the current attitude of the aircraft as determined by the rate of turn and climb shown in the Tracking Task display. In addition, the deviation from the target of the current aircraft heading will be shown by a small arrow around the outside of the attitude indicator. This arrow will come into line with the top of the display as the target heading is reached.

Periodically, you will notice discrepancies in the information (e.g., angle of bank or pitch) being provided by these two instruments where one instrument only will show the correct information. The object of this task is to press the "difference detected" button (F3) as soon as you notice these differences. Two buttons will appear below each instrument indicating which key (F4 or F5) to press to indicate the instrument that is showing the correct information, after which the two instruments will again show the same information. There will be scores deducted for failure to notice these differences in sufficient time as well as "false" alarms and incorrect choice of the instrument showing the correct or "true" information.

BAR TASK:

The lower left display (referred to hereafter as the "Bar Task") will show a number of vertical bars that will change in their length. Beside each bar there is a red line indicating the desired length or "target zones" of the bar. The object of this task is to keep the end of the bars within this range at all times. The bars will change their length periodically and target zones may also change. The length of the bars can be changed in the following way. Use the left and right ARROW KEYS to select a bar (this will be indicated in a change in the colour of the bar). Then use the up and down ARROW KEYS to increase the rate of movement of the bar in the appropriate direction. NOTE: pressing the key once increases the rate of change by one speed in single steps up to a maximum rate. Therefore when the target zone is reached the arrow keys should be used to slow down and or reverse the change in length of the bar to keep it within the target zone. Note that the bar task does not interact with any changes in the other three tasks.