# SCUBA DIVING SIMULATOR: TESTING REAL TIME DECISION MAKING IN A FEEDBACK ENVIRONMENT

by

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B.S., Industrial Engineering, Boğaziçi University, 2003

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Industrial Engineering
Boğaziçi University

2006

# ACKNOWLEDGEMENT

I would like to thank to my thesis supervisor Prof. Yaman Barlas for his guidance throughout this research. I am grateful to Prof. Ali Rıza Kaylan and Assist. Prof. Ali Kerem Saysel for taking part in my thesis committee.

I am grateful to Bogazici University Industrial Engineering, Technical University of Eindhoven and Galatasaray University graduate students, who participated in experiments. Additionally, I would like to thank to members of BUSAS (Bogazici University Underwater Club) and GSUS (Galatasaray University Underwater Club) for their valuable comments and participation in experiments.

I want to express my gratitude to my family for their never ending support. They have been not only affectionate and supportive but also respectful to my decisions.

I am deeply grateful to all of my friends without whom I would not be able to finish this study. I would like to thank especially Özlem Çavuş, Buket Avcı, M. Güray Güler, Elif İbiş, Esin Yaşar, Kurtuluş Barış Öner, Burcu Tan and Özge Karanfil, and finally all the members of the Sesdyn Lab. and Industrial Engineering department for acting like a family and making the department a place like home.

# ABSTRACT


## SCUBA DIVING SIMULATOR: TESTING REAL TIME DECISION MAKING IN A FEEDBACK ENVIRONMENT

In this thesis, human decision making in dynamic environment is studied. A scuba diving simulator, which is converted to a game, is modeled for this experimental study. Different versions and types of the games are played by subjects and the results are studied by analysis of variance method. Latin Square and repeated measures experimental designs are used in statistical analysis.

Most of the dynamic decision making literature analyzes decision making in event driven environments where subjects have plentiful of time before making decisions. However, in our scuba diving simulator, classified as a clock-driven simulator, subjects make decisions continuously throughout the simulation. Since decisions are made continuously, the effect of game speed (time pressure) on performance and on learning is investigated. It is found that game speed is effective on subjects' performances in most of the performance measures. As an extreme case, games with pause option are presented. However, it is observed that performance in games with or without pause option does not differ significantly.

It is a known fact that in general, delays deteriorate performance and learning. In different types of games, material and information delays are added to the structure to account for their effect on performance and learning. Both information and material delays are found to significantly affect the performance. However, performance differences between delay and no delay games are decreased with practice.

Subjects playing games get insight about dynamics of these systems. So, from a similar point of view, subjects who have prior experience might perform better. Although, it is expected that scuba divers will perform better than non scuba divers, no statistically significant difference is found between these two groups. However, performances of subjects differ significantly from each other.

# ÖZET

## TÜPLÜ DALIŞ SİMÜLATORÜ: GERİBİLDİRİM ORTAMINDA GERÇEK ZAMANLI KARAR VERME ANALİZİ

Bu tez çalışmasında, insanların dinamik ortamlarda karar verme süreçleri incelenmiştir. Bu deneysel çalışma için, tüplü dalış simülatörü (ScubaSim) modellendi ve model oyun haline dönüştürüldü. Oyunun farklı tür ve uyarlamaları denekler tarafından oynandı ve oyun sonuçları varyans analizi metodu ile incelendi. İstatistiksel analizde, Latin Kare ve Tekrarlanan Ölçümler tasarımları kullanıldı.

Dinamik karar verme süreçleri alanında yapılan çalışmaların birçoğu, kişilerin karar verirken sınırsız zamana sahip oldukları olaya-dayalı ortamlara aittir. Fakat tüplü dalış simülatörü, kişilerin karar vermeleri için beklenmediği, zamanın bağımsız şekilde aktığı, zamana-dayalı bir simülatördür. Oyun boyunca kesintisiz olarak karar verildiğinden, oyun hızının (zaman kısıtı) performans ve öğrenmeye etkileri incelenebilmiştir. Yapılan analizde, hız etkeninin, performans ölçütlerinin birçoğu üzerinde etkili olduğu görüldü. Uç durum olarak, deneklere oyunu duraklatma seçeneği sunuldu. Fakat bu seçeneğin etkili olmadığı gözlendi.

Gecikmeler, genellikle performansı ve öğrenmeyi kötüleştirir. Gecikmelerin, performans ve öğrenme üzerindeki etkilerini incelemek amacıyla, temel oyun yapısına madde akış ve bilgi işleme gecikmeleri eklendi. Hem madde akış gecikmesinin, hem de bilgi işleme gecikmesinin başarıyı etkilediği görüldü. Fakat temel oyun ile gecikme yapıları eklenmiş oyunlar arasındaki başarı farkının deneyim arttıkça azaldığı belirlendi.

Oyunlar, modellenen sistemlerin dinamiklerinin kavranmasına yardımcı olur. Benzer bir bakış açısıyla, modellenen sistemlerde deneyim sahibi olan kişilerin, oyunlarda daha başarılı olması beklenir. Yapılan çalışmada dalgıçların, daha önce dalış deneyimi olmayan deneklerden daha başarılı olması tahmin edilirken, bu iki grup arasında belirgin istatistiksel bir farklılığın olmadığı görüldü. Bununla beraber, deneklerin bireysel performanslarının istatistiksel olarak birbirlerinden farklı olduğu saptandı.

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| | |
|---|---|
| A | cross sectional area |
| Amp-of-fluct | total amplitude of fluctuations |
| BC | buoyancy compensator |
| Caisson-RI | caisson disease risk index |
| $C_d$ | drag coefficient |
| d | density |
| DDM | dynamic decision making |
| Dev-area-mean | deviation area from mean |
| Dev-mean-10mt | deviation of mean from 10 meters |
| DoF | degrees of freedom |
| Dev-10-mt | deviation area from 10 meters |
| $F_D$ | drag force (N) |
| $F_L$ | lifting force |
| g | gravitational constant |
| h | depth |
| L | characteristic length of the object |
| Max-amp-osc | maximum amplitude of oscillations |
| Max-dev-10 | maximum deviation from 10 meters |
| n | mole of the gas |
| P | pressure |
| R | universal gas constant |
| Re | Reynolds number |
| SS | sum of squares |
| T | temperature |
| $t_{aa}$ | adjustment time of stock a |
| $t_{ax}$ | adjustment time of stock x |
| $t_{av}$ | adjustment time of stock v |
| V | volume |
| $\upsilon$ | velocity |
| $\eta$ | viscosity of the fluid |

# 1. INTRODUCTION AND LITERATURE REVIEW

Dynamic decision making (DDM) studies try to find answers to questions on how human beings control dynamic systems. Renewable resource management, supply chain management, air traffic control are some examples of DDM tasks. DDM is widely studied by economists, psychologists, and system dynamics researchers. DDM researchers may focus on complex problem solving, systems thinking or naturalistic decision making (Gonzalez *et al*, 2005). Although they all try to find answer to the similar questions, their research methodologies vary.

In most of the DDM studies, controlled experiments are carried out for research in complex problem solving and systems thinking areas. As an experimental environment, simulators are created which include characteristics of real world while being simple. On the other hand, naturalistic decision making researchers make observations and interviews instead of controlled experiments. Realism in results is an advantage of naturalistic decision making research, whereas unavailability of experimental validation to support causal results is a disadvantage (Gonzalez *et al*, 2005). It would be more fruitful to combine naturalistic decision making research with controlled experiments.

In this thesis, dynamic decision making under time pressure and in the existence of material and information delays is studied. For this purpose, scuba diving environment is modeled with system dynamics methodology and then converted to an interactive game (ScubaSim). In gaming experiments, subjects try to stabilize at a desired depth while making inflating/deflating decisions continuously throughout the simulation. Although the simulator is small scale one, non linear relationships, implicit/indirect delays, additional delay scenarios and real-time decision pressure make the system hard to control.

To start with a formal definition, according to Brehmer, a dynamic decision task has three main properties. In a dynamic decision environment, series of interdependent decisions are made. The decision environment changes both autonomously and as a result of decisions made. Lastly, decisions are made in real-time (Brehmer, 1990). In the light of these characteristics, ScubaSim is a dynamic decision making environment since subjects give interdependent decisions continuously throughout the game. Each decision affects the system state and also the system state can change autonomously even if no decision is made.

Gonzalez *et al*. classifies and compares microworlds with respect to characteristics of dynamic systems; dynamics, complexity, dynamic complexity and opaqueness. In dynamic systems, the rate of change of a state variable may depend on itself. Such a relationship forms feedback loops in the structure. Feedback loops determine output behavior of the system; oscillations, growth or decay. Dynamic characteristic of a microworld is classified as low when task environment changes only when user makes decisions and high when decisions are made in real-time. ScubaSim, in which decisions are made continuously over time, has dynamic characteristics at high level with respect to the classification made by Gonzalez *et al* (Gonzalez *et al*, 2005).

DDM researches can also be classified into two groups depending on the importance placed on autonomous change in dynamics (Gonzalez *et al*, 2005). As time continuity is central to dynamic systems, some questions arise; for instance, whether cognitive processes in event-driven and clock-driven environments are qualitatively different.

Another characteristic that is used in classification is complexity. Number of components, number of relationships between components and types of relationships determine the complexity of a dynamic system (Gonzalez *et al*, 2005). As the number of relationships between system components increases, any change in a component will also change other system components. These kinds of side effects will increase the complexity of the system. Additionally, it is relatively easy to control a system where relationships are linear compared to a system where relationships are nonlinear. The complexity of ScubaSim can be put under low class with respect to the number of variables and relationships between these variables. But, the relations between most of the variables are nonlinear.

According to Diehl and Sterman, side effects, non linearity in relationships and feedback delays increase the complexity of dynamic systems since decision maker should predict the future state to make decisions (Diehl and Sterman, 1995). Additionally, decisions made will not be effective on the components immediately, but with a delay. This will deteriorate feedbacks received from the system which may result in misperception of the effects of decisions made.

The last characteristic used in classification is opaqueness (Gonzalez *et al*, 2005). It can be defined as the invisibility of components or relationships between components. A component can be accessible but decision maker may not know how to observe the component. ScubaSim has mild opaqueness characteristics since the amount of air deflated/inflated is not accessible.

Individual decision making generally shows large deviations from optimum. Economic aggregate models mostly do not account for this sub-optimality. Sterman utilizes a dynamic decision making environment which aims to explain macro dynamics with microstructure. (Sterman, 1989) Dynamic decision studies may be also conducted to validate or invalidate human decision process structures used in simulation or analytical models.

Grossler classifies simulators into three classes which are event-driven, clock-driven and real-time simulators. (Grossler, 1999) In event-driven simulators, a decision interval is terminated whenever subject makes the decision. On the other hand, in clock-driven simulators, decision interval is finalized after some predefined time period, even if the decision is not given. The decision interval can be enlarged compared to real-time. Lastly, in real-time simulators, which are similar to clock driven simulators, the decision interval is the same as it is in reality. Since the time pressure in real-time simulators is high, it would be appropriate to use clock driven simulators which enable flexibility in the speed of simulation. We will use clock-driven simulators and real-time simulators interchangeably since researchers used real-time environment term for both clock-driven and real-time simulators. The dynamic decision making studies can be divided into two subgroups depending on the type of the simulators: event-driven or clock-driven simulators. Sterman (1989), Diehl and Sterman (1995), Moxnes and Saysel (2004) and Aybat *et al*. (2004) studied dynamic decision making in event driven simulation environments. Brehmer (1990, 1995), Gonzalez (2004, 2005) and Grossler (1999) conducted experiments in clock driven simulation environments in which subjects make decisions continuously throughout the simulation.

Due to Brehmer, there are three main dissimilarities between a real-time dynamic decision task and a traditional decision task (Brehmer, 1990 and 1995). In traditional decision tasks, subject has unlimited time to make decision, but in real-time dynamic task, time will pass and subject will not be waited to make decision. Thus, real-time decision tasks are stressful. Moreover, in real-time decision tasks, subjects do not control events but the processes. Additionally, different decision makers in the same system may make decisions under different time scales and with different information.

### 1.1. Effects of Time Constraints on Performance

Grossler states that proceeding of time is an important aspect of dynamic simulators (Grossler, 1999). For this reason, he conducts experiments in dynamic environment in which a time limit exists on decision intervals. On the other hand, time pressure need to be decreased, so that, decision makers have enough time to analyze the dynamics of the system. The study utilizes a clock driven simulator which represents continuity and time pressure of reality with a feature to slow down the simulation to enable decision makers to get insight about the dynamics. The effect of time pressure on the performance of subjects and learning in clock-driven dynamic decision environment are investigated in the study. The two main hypotheses are as follows: As decision interval gets smaller, performance will be deteriorated and learning will be diminished.

In the explorative study, Grossler uses a simple predator-prey model where subject's goal is to stabilize both populations at levels as high as possible. Decisions may be shooting the prey or shooting the predator, which is in fact very similar to ScubaSim in which subject makes inflating or deflating decision. In one group, decision intervals last 1.6 seconds, whereas in other group it is 0.8 seconds. Surprisingly, subjects playing in shorter decision period get better scores than subjects in longer decision periods. But the difference is not statistically significant. Grossler gives two explanations to these results which in fact contradict the literature. First, the difference may be due to variation between subjects. Second, the relation between time pressure and performance may not be as simple as previously supposed. There may be a range of time pressure which has positive effect on the performance of the subjects. In other words, in longer decision periods, subjects may get bored and lose concentration which results in lower performance (Grossler, 1999).

To investigate the effect of time pressure on learning and performance, Grossler designs another experiment which is simply managing a copy shop. In first treatment group, decision intervals last 15 seconds, whereas in second treatment group, they last 60 seconds. Additionally, in control group there is not a time limit on decision intervals. Pre-test and post-test are applied to subjects to account learning effect under different time pressures. Although there are improvements between pre-test and post-test in all three groups, they are not significant. It is also found that there is not a significant difference between groups in the pre-test and post-test. Thus, hypothesis that as decision intervals get smaller, learning diminishes is rejected. When the average performances of groups are compared, it is seen that treatment group 2 and control group perform significantly better than treatment group 1. Difference between performances of the subjects in treatment group 2 and control group is not statistically significant. It may be attributed to the longer decision intervals of treatment group 2 in which subjects do not perceive any time pressure. As a conclusion, experimental results do not support second hypothesis whereas hypothesis one is partly supported (Grossler, 1999).

Gonzalez has also studied dynamic decision making in real-time. In these studies, a water purification plant, which is a model of mail sorting in the Unites States Postal Service, is utilized. The water purification plant can be classified under the dynamic decision tasks. In the water purification plant, water has to be distributed within treelike structured tanks all of which have a specific deadline. The decision is simply activating or deactivating the pumps which enable to transfer the water (Gonzales, 2004, 2005).

Effects of time pressure and cognitive abilities of subjects on learning are investigated in one of these studies (Gonzalez, 2004). The hypothesis is that time constraints have negative effect on performance but practice can moderate this negative effect. Additionally, relationship between cognitive capacity and performance under time pressure is investigated. It is also questioned whether subjects utilize decision heuristics under low or high time constraints and how these decision heuristics change with practice.

In the game setting, a group of subjects have experience in slow paced games, whereas subjects in control group deal with fast paced game. In the final, all subjects play the fast game. (Practice) x (time constraint) and (practice) x (time constraint) x (cognitive capacity) interaction effects are significant but neither practice nor time constraint is found to be significant on performance. Although it is not statistically significant, subjects experienced in slow paced game outperformed the control group and their performances are also increased through the final phase in which all subjects played fast games. It is postulated that subjects playing slow paced game have enough time to analyze the dynamics and have better control on the system. It is also concluded that mere repetition is not enough to gain insight about the dynamics of the game (Gonzalez, 2004).

Continuing with clock driven simulators, Brehmer has extensively studied effects of feedback delays in dynamic decision making in real-time (Brehmer, 1990 and 1995). A firefighting microworld is utilized to assess the effects of delays on task performance. In this microworld, subjects are in the role of a fire chief who sends fire fighting units to the fires. Subjects are expected to extinguish fires with minimum loss of forest and equipment. There are two main feedback delays which deteriorates controlling the fire. In the first delay type, fire fighting unit needs time to get ready and to reach the fire (dead time delay). In the second delay, fire fighting unit reports after some delay (Brehmer, 1990 and 1995). These two delays are similar to material and information delays in ScubaSim.

In one of these games (Brehmer 1995), it is questioned whether dead time delay has effect on performance different than information delay. In this study, fire fighting task is also modeled as an event driven simulator. In the dead time delay game, fire fighting units responds to commands after 2 time units but there is no delay in reporting. In the information delay case, fire fighting units respond commands without delay, but they report the status after 2 time units. In the no delay game, neither information nor dead time delay exists. (Brehmer, 1995).

When the effect of type of simulation is investigated, it is seen that subjects in event-driven simulator perform better than subjects in clock driven simulator, but there is no significant difference between two groups in learning effects and strategies used. Brehmer states that the effects of feedback delays are the same in event and clock driven simulation. Thus, a quantitative difference may exit but a qualitative difference may not. Type of delay and practice are found to be statistically significant over performance measures. It is seen that information delay group perform better than dead time group but worse than no delay group. With practice, information delay group perform as good as no delay group. It may be seen as an adaptation to the information delay, but Brehmer states that it can be due to time limits. If there is no limitation in the game, results may be different (Brehmer, 1995).

### 1.2. Effects of Delays and Misperception of Feedback

Diehl and Sterman (1995) investigate effects of complexity on performance. Unintended problematic behavior is observed due to *misperceptions of feedback* in complex systems. Existence of multiple feedbacks, delays and nonlinearities in the structure increase the complexity of the system. Performance becomes worse when delay lengths are increased and feedback is strengthened. Decision heuristics that subjects adopt result in systemic, persistent and costly oscillations.

In the extreme form misperception of feedback hypothesis, subjects are expected to completely ignore delays and multiple feedbacks (Sterman, 1989). Thus, performance is deteriorated when there is delay and positive feedback. On the other hand, in the moderate form misperception of feedback hypothesis, subjects may realize the importance of delays and feedbacks but are not able to apply necessary decision heuristics. It is expected to observe low performance in games with delay and positive feedback. However, the results are expected to be similar to optimal when the complexity is rather low such as negative feedback without delay.

In their study, Diehl and Sterman use an event-driven stock management simulator, where the complexity is varied with delays and with the strength of feedbacks. In the game, subjects decide how much to produce to meet the demand and try to stabilize the inventory at a desired level. They should make decisions, so that a negative feedback loop is formed and under the dominance of this feedback loop, inventory is adjusted to its desired level. Although management seems simple, when delays are introduced, it becomes hard to control the system and oscillations are seen in the stock variables. To eliminate the oscillations, subjects should account for supply line (delay in receiving orders). When the decision strategy of subjects are analyzed, it is observed that they mostly ignore the supply line, which means that they do not perceive delays and/or they do not know how to cope with them. Control might be worse when there are multiple feedbacks. Main hypotheses in the study are subjects' performance is deteriorated when complexity of the system increases and subjects adopt different strategies to cope with the complexity of the system (Diehl and Sterman, 1995).

As the observed behaviors in the game are analyzed, it is seen that they are not random; oscillations and phase lags can be seen as evidence of systemic errors. This type of behavior is also observed in business cycles of actual economy. The macroeconomic problematic behavior, business cycles, is observed in the micro level.

Diehl and Sterman (1995) use two benchmarks, full state variable feedback rule and no control rule. In full state variable feedback rule, decisions are made with respect to the current values of all state variables; inventory, production order, inventory in production and sales. When the subjects' behavior compared with the benchmarks, it is observed that subjects mostly outperform no control rule but in games with high delays and positive feedback. The difference between subjects' performances and no control rule is significantly affected by length of delays and feedback strength. When the comparison is made between optimal rule and general behavior of subjects, it is seen that performances are nearly parallel. The difference is not affected by the complexity of system, delays and feedback strength. This supports that subjects adjust their decisions under delays and different feedback delays (Diehl and Sterman, 1995).

In one of his studies, Brehmer tests whether subjects fail to recognize delays even they have enough information to infer them. In delay condition, fire fighting units report after some delay, whereas in control group there is no delay in reporting. Each subject is informed about the possibility of delays. At the end of experiments, subjects are asked whether they face with delays or not and if they state existence of a delay, the length of delay is asked. All subjects in delayed condition report existence of delays but they believe that fire fighting units are slow in responding to the commands whereas in reality the delay lies in reporting. When performances of two groups are compared, it is seen that subjects in no delay condition perform significantly better than delay group. Time period in which fire fighting units are inactive are statistically different between groups and the difference closely corresponds the information delay. Although subjects are informed about the possibility of existence of information delay, they can not develop a strategy for delay (Brehmer, 1995).

In the next experiment, it is examined whether information about the type of delay will improve performance. Four groups are formed depending on the type of delay included in the structure (information delay and dead time) and information given to the subjects about delay (no information and information). Performance in information delay games is better than the performance in dead time delay. There is not a significant effect of information about delays. When subjects are informed about delay, results are very similar to those obtained in previous experiment, where the information about the type of delay is not available to the subjects. Brehmer states that the situation can not be attributed only to misperceptions of feedback hypothesis. Subjects also face with problems in finding a way of compensating for the delays (Brehmer, 1995).

Moxnes and Saysel study people's perception of $CO_2$ emissions and climate change with laboratory experiments in which subjects are expected to stabilize $CO_2$ concentration with making emission decisions. In the model structure, there is an extreme case of information delay such that outcome feedback is not provided (except one treatment). Although the model used in experiments is very simple, subjects can not stabilize at desired level. This poor performance is attributed to usage of static mental models in a dynamic decision task. There are four treatments in the experiments. With the physical analogy of the $CO_2$ system in which subjects are expected to stabilize air in a balloon, performances are improved. When the physical analogy is given as an information treatment, performance is not differed from base case. Another information feedback, absorption information, does not improve performance either. When the simulator is stopped after each decision, feedback and additional time for making decision are provided, performance is significantly improved. Results show that people misperceive basic dynamics of $CO_2$ emissions and they are not able to use appropriate dynamic mental models instead of static ones (Moxnes and Saysel, 2004).

Aybat *et al*. study dynamic decision by utilizing controlled experimentation in event-driven simulators. The hypothesis is that subjects' performance will be worse in more complex systems since the clarity of feedback will be deteriorated by increasing complexity. Complexity of the system is increased by introducing delays and enabling control with secondary stock. The results of games show that delay and secondary stock control have statistically significant effect on performance whereas the interaction effect is found to be insignificant (Aybat *et al*., 2004). When the game structure used in that study is compared with ScubaSim, it is seen that in ScubaSim subjects try to control the desired stock not with a secondary stock but with a third order stock.

### 1.3. Strategies Used by Subjects

Experimental results support that subjects are insensitive to feedback which forms the basis for misperception of feedback hypothesis. The "Beer Game" contains multiple feedbacks, non-linearities and delays which can be classified as a complex dynamic decision environment. In this environment, subjects' behaviors systematically differ from optimum, since subjects generally do not take into account feedbacks. When anchor and adjustment rule is applied for modeling the decision process of the subjects, it is seen that the fit is satisfactory. In the anchor and adjustment rule, decision makers utilize the information for two main adjustments for controlling the inventory. Firstly, any difference between inventory and desired inventory should be reduced. Secondly, there should be some inventory on order to account for sales. Additionally, inventory decreased by sales should be replaced with new orders (Sterman, 1989).

For each subject, parameters of anchor and adjustment decision rule are estimated and simulated results are compared with real game results. After the accuracy of the proposed rule is accepted, it is used for analyzing the reasons for under control. It is found that desired supply line stock and weight given to supply line are lower than optimum ones (Sterman, 1989).

Diehl and Sterman (1995) test two models for subjects' decision processes. The first model utilizes all information available to the decision maker, whereas the second model includes only inventory, sales and recent production decision but not inventory in production. For the first model, in no delay condition, estimated values are generally smaller than optimal values, showing significant under control. When delays are present, the degree of under control is increased. It is also found that subjects do not utilize inventory in production data which supports moderate misperception of feedback hypothesis. However, some subjects do not even use recent production data which supports extreme misperception of feedback hypothesis. For the second model, the difference between estimated coefficients and optimal coefficient values are tested, it was observed that difference is significant and estimated coefficients are generally smaller than optimal values which supported undercontrol as in the first model (Diehl and Sterman, 1995).

Brehmer also investigates strategies used and their relation with feedback delays. It is proposed that subjects usually use the same strategy in delay and no delay conditions. Within an experimental setting, it is also investigated whether different strategies are applied in different delay settings. In experiments, one of four groups initially faces with delay whereas another group plays no delay game. Then, they switch the condition in the last two trials. The two control groups play the game in the same condition throughout the trials; one in delay condition and the other one in no delay condition. Subjects, who initially play without delay, after the shift, perform the same as the subjects who play delay games throughout trials. On the other hand, subjects, who initially play games with delay, improve their performances after shift, but they are not successful as much as the subjects' who play no delay game throughout trials. It is seen that subjects adopt different strategies under delay and no delay conditions (Brehmer, 1995).

In another study, Brehmer utilizes fire fighting game setting to analyze the strategies used. He names the two strategies as feedforward and feedback strategies. In feedforward strategy, subject makes decisions depending on the predictions of future state of the system. When the task is transparent to the subject, predictions of future states will be possible and feedforward strategy can be utilized. A transparent task is the task where reasons can be attributed to the delay. The task becomes opaque where reasons for delays can not be seen. On the other hand, in feedback strategy, which is simpler than feedforward, subject makes decisions depending on the current state of the system. It will possibly be applied when the task is not transparent and subject can not predict the future states. In real life, delays always exist. Thus, subject should make decision before feedback from the system signals the requirement of the decision. Since feedback strategy is simpler than feedforward strategy, needs less cognitive effort and if a reasonable level of success is enough for decision maker, he may choose to adapt feedback strategy even delays are present. (Brehmer 1990).

### 1.4. Effects of Different Types of Feedback on Performance

Gonzalez tests decision support tools for real-time dynamic decision making. Since in real-time environments, decision makers deal with time pressure, decision support tools will be useful to make better decisions in limited time. In the study, different types of feedback are utilized to investigate their effects on performance. Outcome feedback can be described as screening performance results through simulation. Although frequent and detailed outcome feedback is needed for better performance, it can be classified as an inefficient decision support tool. The subjects in control group receive some base outcome feedback, whereas feedback group receive a frequent outcome feedback. In cognitive feedback group, decision makers are given explanation about how to perform the task. Gonzalez hypothesizes that cognitive feedback will improve task performance in future trials. Subjects in self exemplar group have opportunity to review their previous games. In feedback exemplar group, subjects receive frequent feedback and have the opportunity to replay their previous games. With replay option, subjects get insight about decision task, since they do not have enough time during games. Additionally, feedforward decision support is used to analyze the effects of possible future decisions. In expert exemplar group, subjects have opportunity to review experts' trials. It is hypothesized that reviewing experts' trials will improve performance. After practice trials, subjects execute trials with only outcome feedback (Gonzalez 2005).

Practice is significant on the performance of the subjects. There is not a significant difference control group, outcome feedback, self exemplar and feedback exemplar. On the other hand, difference between control group and expert exemplar is significant. Subjects in the feedback group, who received detailed feedback, have poorer performance than control group and with practice they are able to catch them. When the similarity of subjects' decisions to expert decisions is analyzed, it is found that average similarity of expert exemplar group is higher than the average similarity of control group. The similarity of expert exemplar subjects' decisions and experts' decisions can be seen as evidence to instance base learning theory where subjects accumulate instances of experts' decisions (Gonzalez, 2005).

In instance based learning theory, it is hypothesized that decision makers store action-outcome pairs. Subjects call action-outcome pairs as the decision environment becomes similar. Instance based learning theory proposes that these action-outcome instances are stored with the utility information. When a new action-outcome pair is experienced, the utility of the instance is further evaluated and learning occurs. In every decision situation, highest utility instance is called (Gonzalez *et al.*, 2003).

# 2. PROBLEM DEFINITION AND OBJECTIVE

Dynamic decision making studies show that strategies used and behaviors observed usually deviate from optimum ones due to dynamic complexities; delays, feedbacks and non-linearities. People can not develop necessary mental models to cope with complex systems. They either do not realize delays and non-linearities or do not know how to deal with them. Thus, oscillations, which bring extra costs and other burdens, are observed in the existence of delays. Feedbacks and non-linear relationships between variables make hard to predict the future behavior. Moreover, in real life dynamic decision making, time pressure is another complexity that deteriorates performance. In this study, the goal is to evaluate the effects of delays, time pressure and prior subject experience on performance, in a non-linear real-time dynamic decision making environment.

For this purpose, a system dynamics model of scuba diving is developed. The model is converted to an interactive game. In the game, subjects try to stabilize at a desired depth by making air inflating/deflating decisions continuously throughout the simulation.

People make decisions depending on feedbacks they received from environment. In the existence of delays, the effect of action will be observed after some time. Thus, the feedback clarity will be decreased and decision-outcome pairs may become inaccurate. In the ScubaSim game, depth variable is controlled indirectly via a third order stock. Material delay and information delay structures will also be added to basic structure. The effects of delays on performance and learning will be investigated.

Most of the dynamic decision literature dedicated to decision making under unlimited time. However, decision behaviors in more realistic environments with time pressure should be studied more extensively. Thus, ScubaSim is modeled as a clock-driven simulator in which decisions are made continuously through the simulation. To account the effects of time pressure, simulation games will be played under low and high time pressure.

It is logical to hypothesize that people having experience (scuba diving) and proper mental models to control the system, may perform better than usual subjects. To evaluate the effect of prior knowledge, a group of scuba divers will play the same game, to be compared with non scuba divers.

Another question that rises about learning in dynamic decision environments is whether the performance will improve with practice. In the literature, it is also questioned whether performance improvement is an indication of learning.

If differences between subjects are not taken into account in statistical analysis, the significance of results of different factors will be masked. Therefore, significant differences between subjects will also be investigated.

To find answers to these questions, laboratory experiments will be carried out. Different types and versions of ScubaSim will be played by subjects; scuba divers and non scuba divers. Proper experimental designs will be used in statistical analysis of material and information delays, time pressure, prior experience and practice on subject performance.

# 3. THE SCUBA DIVING MODEL

In this thesis, Scuba Diving environment is modeled as a dynamic decision making environment. In the first part of this section, causal relationships among variables will be presented. Then, model structure will be shown with stocks, flows and auxiliary variables. After presenting formal model, basic formulations will be discussed under model equations and structure validation section. The two equations which are at the heart of the system are drag force formulation and flow rate formulation and they will be discussed in that section. The validation of the model will continue with selecting an appropriate integration step, also called dt. After presenting a valid model of scuba diving system, some base behaviors with different decision heuristics will be presented.

In scuba diving, the diver regulates buoyancy with deflating air from or inflating air into buoyancy compensator (BC). With a neutral buoyancy, divers stay where they are. On the other hand, with positive buoyancy, diver rises without any effort. Contrary to positive buoyancy, divers with negative buoyancy increase their depth without any extra effort. Thus, controlling buoyancy stays at the heart of the system.

Apart from buoyancy concept, hydrostatic pressure, ideal gas equation and lifting force are three physics laws that act on the scuba diving system. To start with the first law, the pressure acting on a unit area of the object by the weight of the fluid, plus any pressure acting on the surface of the fluid is called hydrostatic pressure. The hydrostatic pressure depends on depth (h), density of the fluid (d) and gravitational constant (g). It is formulated as $P=h*d*g$. When the density variation with depth is neglected, each and every 10 meters increase in depth, corresponds to one atm pressure increase. Since the pressure acting on the surface of the sea is one atm; the pressure can be formulated as 1+depth/10, where unit of depth is meter.

The second law that is effective on the diving system is the ideal gas equation. The three gas laws, Boyle, Charles and Avogadro, when combined, form the ideal gas equation. The equation can be written as $P*V=n*R*T$, where P is pressure, V is volume of the gas, n is the mole of the gas, T is the temperature and R is a universal constant. While depth increases without any change in mass of the gas, higher pressure acting on BC will decrease its volume. Using the same equation, we can say that to have the same volume at deeper, air must be added to BC.

The third law is about the lifting force acting on the BC. The lifting force acting on an object with a volume V is formulated as F= V*d*g, where d is the density of the liquid and g is the gravitational constant.

The other force acting in the diving system is frictional force, also called drag force. The drag force acting on a moving object in a fluid with a velocity v is formulated as F= $½*C_d*A*v^2*d$, where A is cross sectional area of the object and d is the density of the fluid. $C_d$ is coefficient differs with the shape of the object. The $C_d$ value can be assumed to be constant if Reynolds' number is larger than 1000 (Munson *et al.,* 2002).

One of the challenging jobs is to formulate the drag force. Since the shape of diver is not simple enough to use formulas in text books, we evaluated drag force in different velocities with different radius. Also, drag coefficient values are estimated. When the estimated results are compared with experimental drag forces, it is seen that there is no significant difference. So, it would be simpler and convenient to use single drag coefficient for different velocities with different radius. Further validation will be shown later in model equations and structure validation section.

### 3.1. Causal Loop Diagram

Causal loop diagram gives fundamental view of dynamics with minimum complexity. Before the model is formulated in detail, essential variables and basic relationships among those variables must be clearly defined with respect to problem definition.

In the model, depth is defined as the difference between current location and surface. It increases while moving downwards. Like depth variable, all force variables have magnitudes and directions. Contrary to regular convention, the positive direction will be downwards while negative direction will be upwards as seen in Figure 3.1.

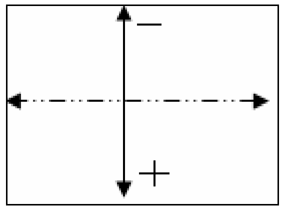



Figure 3.1. State space direction signs

For simplicity, initially causal loop diagram of a frictionless system is presented (See Figure 3.2). An air increase in BC results in volume increase of the BC. Any volume increase results in increase in lifting force. As lifting force increases, net force decreases and when net force decreases, acceleration decreases. Acceleration decrease results in decrease in velocity increase. As velocity decreases, depth decreases and this results in pressure decrease which eventually increases volume. The sign of the loop is positive. Let's call this loop as lifting reinforcing loop. As air is increased, the reinforcing loop will start to work and will result in more increase in volume of BC. The same process also works in the opposite way, where initial volume decrease results in additional volume decrease.

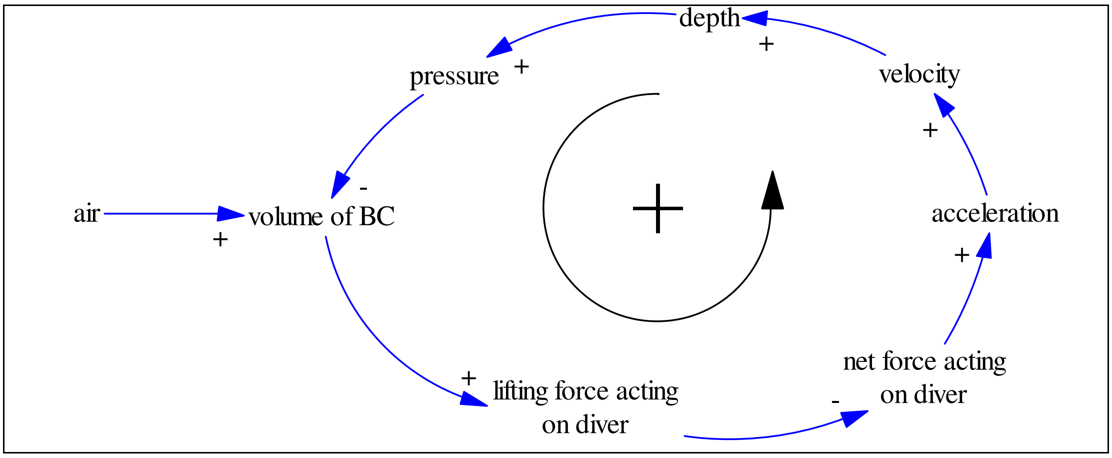



Figure 3.2. Causal loop diagram of ScubaSim when friction is neglected

The lifting reinforcing loop remains the same even if the drag force is not neglected. There are different formulations of drag force depending on the velocity and shape of the body. Although the cross sectional area affects drag force, it would bring complexity to decision process which is to be analyzed. As will be shown and validated in model equations and structure validation section, drag force formulation will only depend on velocity of the body.

When velocity increases, magnitude of drag force increases. Drag force acts against to the motion. Thus, velocity increase causes decrease in drag force. As drag force decreases, net force acting on diver also decreases. Net force decrease results in acceleration and velocity decrease. This relation closes the negative feedback loop, which is called drag force balancing loop (See Figure 3.3). Although there are some other auxiliary variables and constants, fundamental variables are shown in this causal loop diagram.

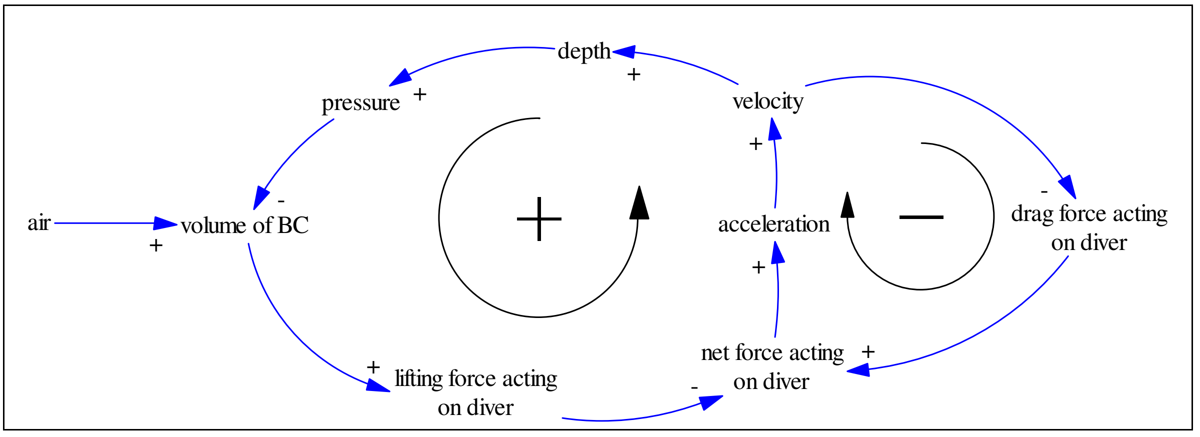



Figure 3.3. Causal loop diagram of ScubaSim when friction is present

Drag force balancing loop, works to nullify the net force acting on diver. The resulting velocity is called limiting velocity. This balancing loop precludes reaching very high speeds. As in real life cases, drag force or frictional force helps to control systems.

Subjects' decision processes and their relation with the system may be also added to the causal loop diagram. Subjects are expected to control the system with using appropriate decision heuristics. In these heuristics, subjects may utilize depth and velocity data. By comparing actual depth and velocity data with desired values, subjects will make deflating/inflating decisions. Although heuristics may differ from subject to subject, main structure of control is expected to be similar (See Figure 3.4). Since decision processes of subjects are unknown, sign of relationships are not given at this point. But it has to be stated that to control the system, subjects must form balancing loops or negative feedback loops.

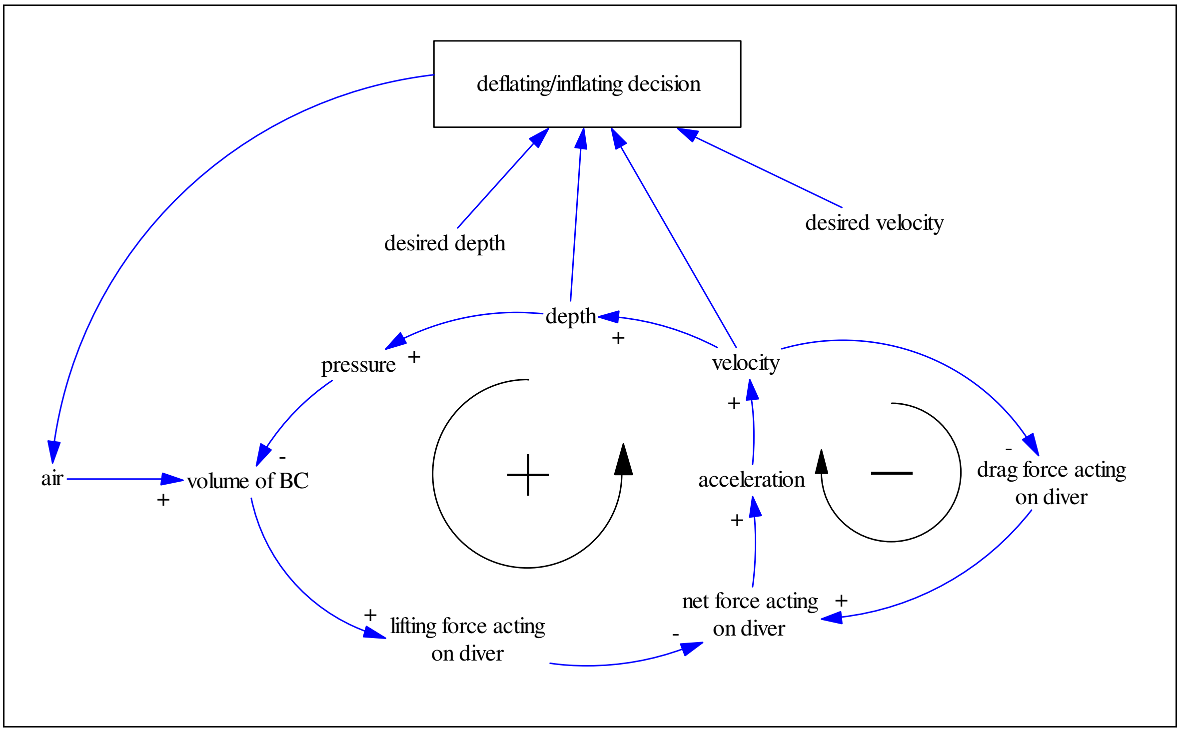



Figure 3.4. Causal loop diagram of ScubaSim when human decision process is added

## 3.2. Stock-Flow Diagram

The stock flow diagram of the model can be seen in Figure 3.5. There are three stock variables: *Depth, velocity and air*. These variables can only be changed via their inflows or outflows. The rate of change of *depth* is *velocity* and it is a biflow which means that it may take positive and negative values. The unit of depth is meter. The rate of change of *velocity* is *acceleration* and it is also modeled as a biflow. The unit of velocity is meter/second whereas meter/second$^2$ is used as the unit of acceleration. The stock variable *air* is changed by *air flow* and it is a function of *air adjustment decision*. Finally, *disturbance* outflow is used only once at t=5, to disturb the system from its equilibrium for games initialized at 10 meter depth. The unit of air is mole.

The left part of the stock flow diagram can be seen the main structure of the model, whereas the right part includes some constants and volume calculations.

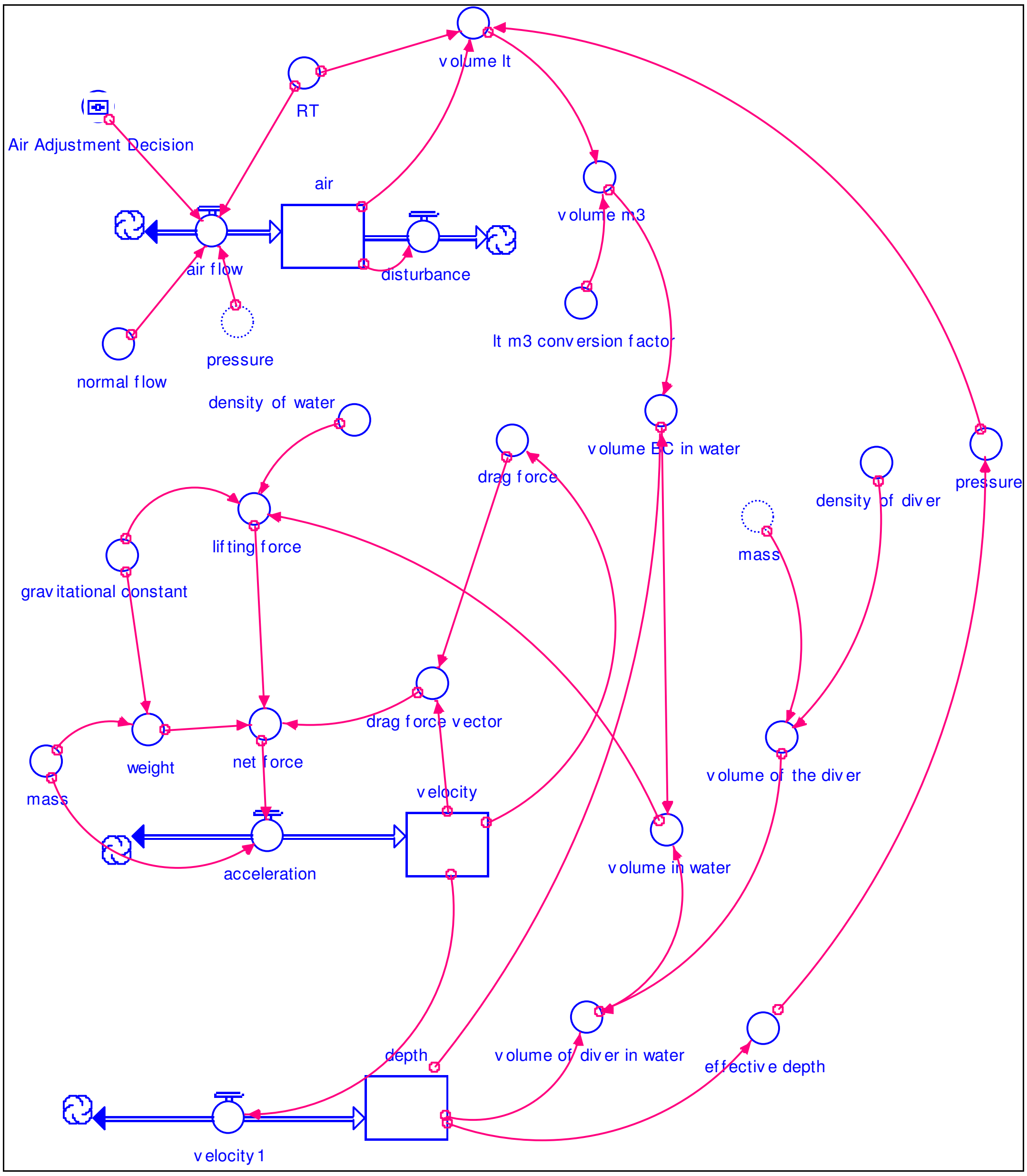



Figure 3.5. Stock-flow diagram of ScubaSim

## 3.3. Model Equations and Structure Validation

Complete list of model equations can be seen in Appendix A whereas in this section only key equations will be shown. Firstly, stocks and their flow equations will be analyzed. Starting with air stock, its initial value is formulated as pressure*(90-volume_of_the_diver * 1000)/RT which enables diver to stay in equilibrium initially. Net force acting on diver must be equal to zero which necessitates that lifting force, V*d*g, should be equal to weight of the diver, m*g. From this equality total volume equals m/d. Mass of the diver, which also includes diving equipment, is decided to be 90 kgs where mass of the diving equipment may take values between 15-25 kgs. Thus, total volume, that nullifies the net force acting on diver, should be 90 liters. However, diver has also a volume, *volume_of_the_diver*. Since unit of *volume_of_the_diver* is $m^3$, it should be multiplied by 1000 to evaluate the volume in liters. The difference between these two values gives the required air volume. From ideal gas equation, required air mole is found by pressure*(90-volume_of_the_diver*1000)/RT formulation (See Equation 3.1).

air(t) = air(t - dt) + (air_flow - disturbance) * dt (moles)

INIT air = pressure*(90-volume_of_the_diver*1000)/RT (moles) (3.1.)

INFLOWS:air_flow=Air_Adjustment_Decision*normal_flow*pressure/RT (moles/sec)

OUTFLOWS: disturbance = PULSE(air/4,5,0) (moles/sec)

The air flow volume has complex dynamics in reality. There are a number of factors acting on air flow volume. Pressure acting on BC, amount of air in the BC and speed of air flow are main factors effecting air volume passing through inflating/deflating tube. In ScubaSim, it is decided to use *constant volume change* for a given duration of air flow application. There are two reasons for taking constant volume change. Firstly, constant flow volume is decided to be adequate approximation of flow. Secondly, since the model will be turned to a game, parameters effecting the decision should be as few as possible and structure should be as simple as possible. If constant mass change were used, the volume change at each depth level would be different and such a difference would complicate the game. Thus, the change of air volume per second is taken to be constant (or zero when not applied). So, each deflating (inflating) decision will increase (decrease) the same amount of air volume per unit time. Since the unit of air is mole, volume change has to be converted to mass change which is done by simply multiplying with pressure/RT, where T is the temperature and R is universal constant. Since both T and R are constants, their multiplication, 0,082 and 304 $K^{\circ}$, is taken to be 25. Additionally, in some versions of game, subjects are initially faced with disturbance flow. This disturbance flow causes a loss of ¼ of the initial air stock at t=5 (See Equation 3.1).

Air adjustment decision is the decision variable and may take -1, 0 or +1 where -1 corresponds to opening valve to deflate air, +1 corresponds to opening valve to inflate air and 0 closing both valves. At each time instance, air adjustment decision must take one of these three values (See Equation 3.1).

depth(t) = depth(t - dt) + (velocity1) * dt (meters)

INIT depth = You_are_at_10_mt_depth_but_there_is_disturbance_Stabilize_at_10_mt*10

+You_are_at_20_mt_depth__Stabilize_at_10_mt*20 (3.2.)

+You_are_at_the_surface__Stabilize_at_10_mt*0

INFLOWS:velocity1 = velocity (meter/sec)

Depth is the main variable to be controlled. Its initial value changes depending on the version of the game. Subjects may start at surface, at 10 meters or at 20 meters (See Equation 3.2).

The equipment includes a metal air tank and scuba diving suit. They roughly compensate each other and density of the diver-equipment system remains the same with the density of human body. Thus, not to include too many variables, density of diver is used instead of density of diver-equipment system.

$$drag\_force = 27.2*velocity^2 \text{ (N)} \quad (3.3.)$$

One of the most challenging modeling issues is formulating the drag force. The drag force acts opposite to the direction of the motion. In other words, drag force always tries to stop the motion.  The magnitude of the drag force depends mainly on relative velocity of the object to the fluid, the cross sectional area of the object and density of the fluid. The formulation use in modeling drag force can be seen in Equation (3.4).

$$F_D = \frac{1}{2} * C_d * A * d * v^2 \quad (3.4.)$$

The drag coefficient, $C_d$ is not always constant; it depends on the velocity of the object, viscosity of the fluid, shape of the body and roughness of the surface of object. Reynolds number is used to characterize the dependence of drag coefficient to the relative velocity of the object (See Equation 3.5). For small values of Reynolds number (for nonturbulant flows) drag force is proportional to the velocity of the object. For large values of Reynolds number (flow is turbulent) drag coefficient is almost constant (See Equation 3.6 and Equation 3.7).

$$\mathrm{Re} = \frac{L * d * v}{\eta} \tag{3.5}$$

$$\mathrm{Re} < 1 \Rightarrow F_D \approx -kv \tag{3.6}$$

$$\mathrm{Re} > 1000 \Rightarrow C_d \approx constant \tag{3.7}$$

The shape of the diver is not one of the basic objects. In this respect simulations are done to determine the drag force acting on diver with different velocity and radius properties. The shape of our diver used in simulation model can be approximated as in Figure 3.6.

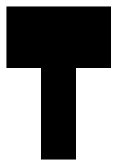


Figure 3.6. Approximated shape of diver used in simulation model

The motion will be vertical. Although the cross sectional area perpendicular to the motion will remain same on both directions, drag force acting on the object on different sides are expected to be different because of the aqua dynamic properties of diver in different directions of motion. For this reason simulation runs are made for different directions to estimate the drag force acting with different velocity and radius properties with the program called Fluent (Fluent 6.1 User's Guide).

Table 3.1. Drag force acting on diver when motion is downwards

| | | **Radius (m)** | | |
|---|---|---|---|---|
| | | **0,15** | **0,2** | **0,3** |
| **Velocity (m/sec)** | **0,1** | 0,29 | 0,42 | 0,91 |
| | **0,5** | 7,2 | 10,47 | 22,59 |
| | **1** | 28,77 | 41,83 | 90,29 |
| | **1,5** | 64,69 | 94,07 | 203,17 |
| | **2** | 114,99 | 167,21 | 361,05 |
| | **2,5** | 179,61 | 261,23 | 564,05 |

Table 3.2. Drag force acting on diver when motion is upwards

| | | Radius (m) | | |
|---|---|---|---|---|
| | | **0,15** | **0,2** | **0,3** |
| Velocity (m/sec) | **0,1** | -0,38 | -0,59 | -1,39 |
| | **0,5** | -8,35 | -14,57 | -34,75 |
| | **1** | -33,32 | -58,23 | -138,9 |
| | **1,5** | -74,93 | -131 | -312,4 |
| | **2** | -133,2 | -232,8 | -555,4 |
| | **2,5** | -208,1 | -363,8 | -867,9 |

In game environment, the velocity of the diver takes values up to 2 m/sec. Although it may take larger values, they can be classified as outliers. The radius of the diver takes values between 0.13 m and 0.2 m. The results of the simulations for estimating the drag force in different directions can be seen in Table 3.1 and Table 3.2. As seen in Table 3.1 and Table 3.2, magnitude of the drag force acting on the object while moving upwards is larger than while moving downwards with the same speed and radius. Although drag force acting on the object differs depending on the direction of the motion, due to the objective of this study, it does not have significant importance. It will be more appropriate to use a single average drag force between these two levels.

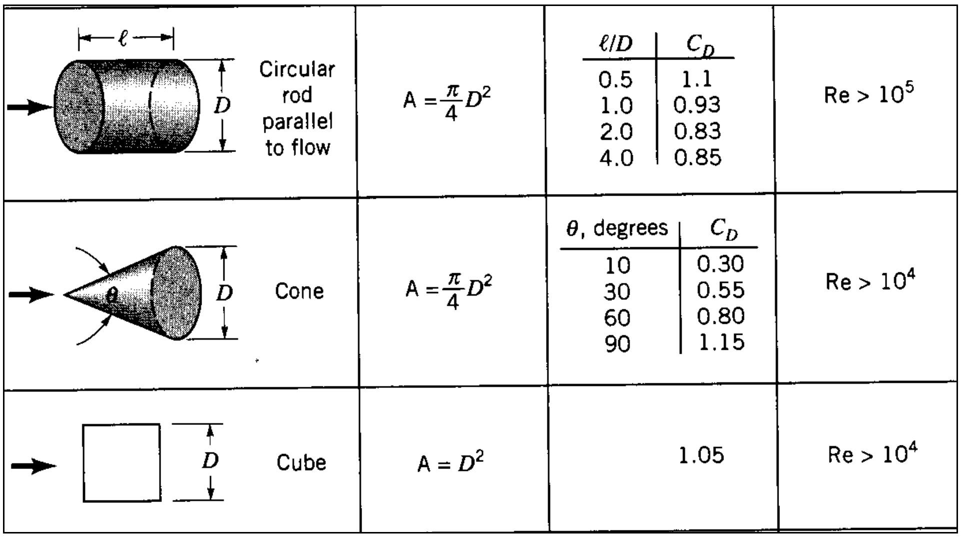



Figure 3.7. Typical drag coefficients for regular three dimensional objects (Munson *et al.,* 2002)

The next step is to determine the value of $C_d$ and validate the formulation of the drag force with respect to drag force figures obtained by simulation runs. Firstly, velocity range must be decided where Equation (3.7) is valid. The velocity must be at least $10^{-3}$ order for applying Equation (3.7). In the simulation runs, such speed limit is passed only in one or two simulation steps. Thus, Equation (3.7) may be used throughout simulation. Secondly, range of Reynolds number values is analyzed. The velocity of the diver will change between $10^{-1}$ and $10^{1}$ order. Reynolds number in this range is in the order 104 and 106. For different shapes, drag coefficients for this range are searched (See Figure 3.7). Since the diver may use hands and fins during diving, $C_d$ should be adjusted somewhat larger than these values. It is decided to use 0.8 as $C_d$ value.

At the next step, the drag force formulation is tried to be simplified without changing dynamics of system. As mentioned previously, cross sectional area of the diver is changed with changes in the volume of BC. However, cross sectional area change is not significantly affecting the behavior of the system. Thus, a fixed cross sectional area may be used throughout the simulation and motions in both directions.

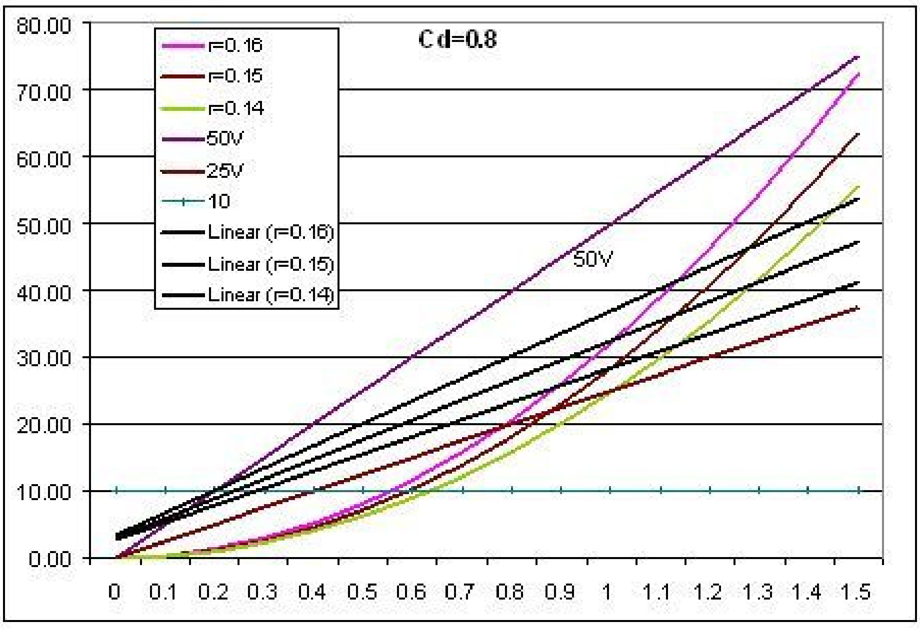



Figure 3.8. Drag force values for different radius with linear and quadratic formulations

The simplification process is continued with drag force and velocity relationship. Drag force is a function of $\upsilon^2$. It is investigated whether a linear relationship can be adequate in this case. When drag force is plotted for different cross sectional areas with linear and quadratic formulations, Figure 3.8 is obtained. As seen in the figure, there are significant pattern differences between two formulations. Thus, it is decided to use a constant $C_d$=0.8 and r=0.15 and $F_D$=(1/2)*0.8*3*$(0.15)^2$*1000* $\upsilon^2$=27,2* $\upsilon^2$.

However, one more step is needed to complete drag force which determines its direction. Since drag force will be opposite to direction of motion, if-then-else function is utilized for defining direction and magnitude of drag force (See Equation 3.8).

drag_force_vector = IF(velocity=0)
THEN(0) (3.8.)
ELSE(-velocity/ABS(velocity)*drag_force) (N)

Depth is measured as the difference between sea level and head of the diver. The BC surrounds the upper 0.5 meters part of the diver. Thus, average pressure acting on BC depends on the average depth of BC. Effective depth formulation is utilized to determine the average depth of BC (See Equation 3.9).

effective_depth = IF(depth<-0.5)
THEN(0)
ELSE(IF(depth<0) (3.9.)
THEN((0.5+depth)/2)
ELSE(depth+0.5/2)) (meters)

As mentioned in the beginning of the chapter, the lifting force acting on an object in a fluid equals to $F_L$=-V*d*g (See Equation 3.10).

lifting_force = -volume_in_water*gravitational_constant*density_of_water (N) (3.10.)

Air flow volume per unit of time is modeled to be constant. When flow volume of a real BC is measured, it is found that it is around 1 liter/second. However, in different versions of game, we use 3 liters/second as the flow volume to evaluate its effect on performance.

The following two formulations, which seem to be complicated, calculate the volume of BC and volume of diver under the water. If the depth is larger than zero, it means that diver and BC is completely under water. If depth is smaller than -0.5, then BC is out of the water. Between these two values, volume of BC under water is calculated as in the formulation. Similar relationship is valid for the diver where his height is taken as 1.5 meters. Thus, if the depth is between 0 and -1.5, volume of the diver under water is found by following formulation (See Equation 3.11 and Equation 3.12).

volume_BC_in_water = IF(depth<-0.5)
THEN(0)
ELSE(IF(depth<0) (3.11.)
THEN(volume_m3*(0.5+depth)/0.5)
ELSE(volume_m3)) ($m^3$)

volume_of_diver_in_water = IF(depth<-1.5)
THEN(0)
ELSE(IF(depth<0) (3.12.)
THEN(volume_of_the_diver*(1.5+depth)/1.5)
ELSE(volume_of_the_diver)) ($m^3$)

### 3.4. Decision Heuristics and Dt Verification

The diving process in real life is a continuous decision process. But in digital gaming environment, discrete approximation must be used instead of continuous. The discrete approximation must be verified to be an adequate representation of continuous version. For this reason, simulation step, dt value must be small enough to represent continuity while being large enough to provide a feasible and fast enough simulation.

For this analysis, three different air flow decision heuristics are used. Additionally, the game data of a player is also utilized. These four structures are run with various dt values and appropriate dt value is selected.

The procedure is to start with a relatively large dt and keep running the same simulation with smaller dt values. When we observe that a smaller dt value yielding a simulation output that is basically the same as the preceding (larger) dt, we conclude that the dt value is small enough.

### 3.4.1. Decision Heuristic 1

In the first simple decision heuristic, air adjustment decision is made with only respect to depth. If the depth of diver is larger than 10.5 mt, deflating decision is made. If depth is smaller than 9.5 mt, inflating decision is made. If the depth value is between 9.5 mt and 10.5 mt, neither inflating nor deflating decision is made. In the simulation runs, the same disturbance is used: Pulse (air/4, 0, 0). Moreover, integration method may affect the output behavior. So, runs are taken with Euler and Runge-Kutta 4 integration methods. Flow volume is used as 4 liters/second.

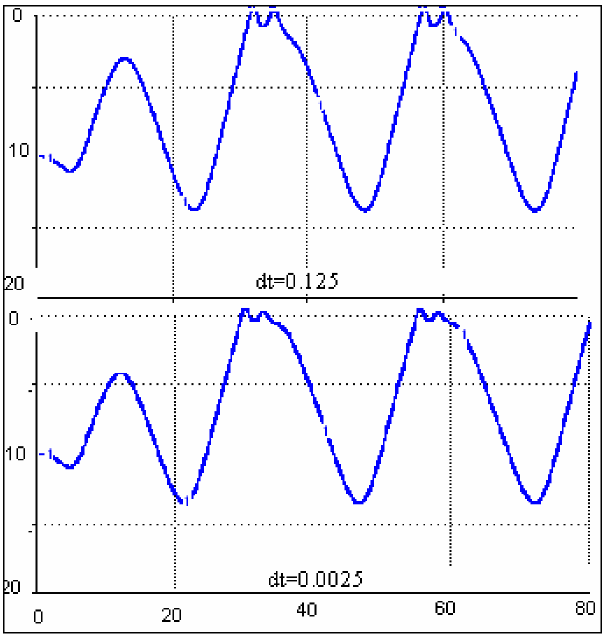



Figure 3.9. Typical results obtained with Euler method

All the runs with Euler integration method give satisfactory results. Two typical results can be seen in Figure 3.9 and the other outputs can be seen in Appendix B.1. There is not a behavioral difference between runs, so all dt values as large as 0.125 can be classified as satisfactory.

When the same decision heuristic is used with Runge-Kutta-4 integration method, output behaviors similar to those in Figure 3.10 are obtained. Other output behaviors can be seen in Appendix B.1. Since there is not a behavioral difference between runs with different dt values, the value as large as 0.125 can be classified as satisfactory.

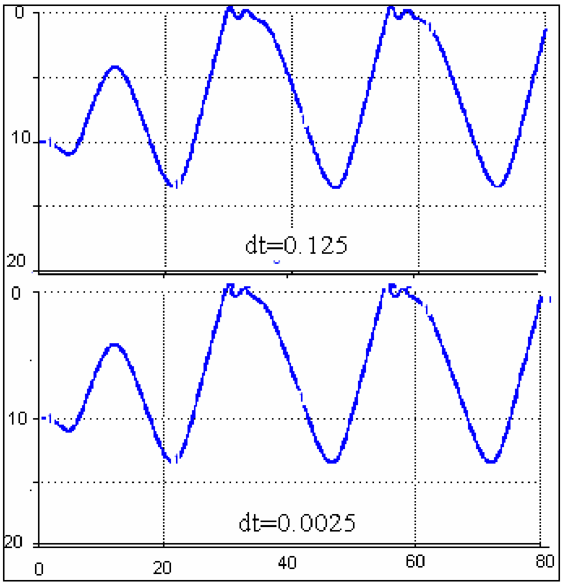



Figure 3.10. Results with Runge-Kutta4 method

### 3.4.2. Decision Heuristic 2

In this heuristic, air adjustment decision is made with respect to velocity and depth values. Firstly, discrepancy between desired depth and actual depth is found. This discrepancy is tried to be nullified after a depth adjustment time, 10 seconds. Thus, the desired velocity equals the discrepancy divided by 10 seconds. If actual velocity is larger than desired velocity, then inflating decision is made. If actual velocity is smaller than the desired velocity, then deflating decision is made. If they are equal, then neither deflating nor inflating decision is made (See Equation 3.13).

$$\frac{x^{*}-x}{10}=v^{*} \quad \text{Air adjustment decision} = \begin{cases} \text{inflating} & v^{*} > v \\ \text{deflating} & v^{*} < v \\ \text{neither inflate nor deflate} & v^{*} = v \end{cases} \qquad (3.13.)$$

Although, it seems that air adjustment decision is made only with respect to velocity value, the decision process inherently includes depth adjustment in desired velocity term. Additionally, disturbance is formulated as follows: Pulse (air/4,0,0) Flow volume is used as 4 liters/second.

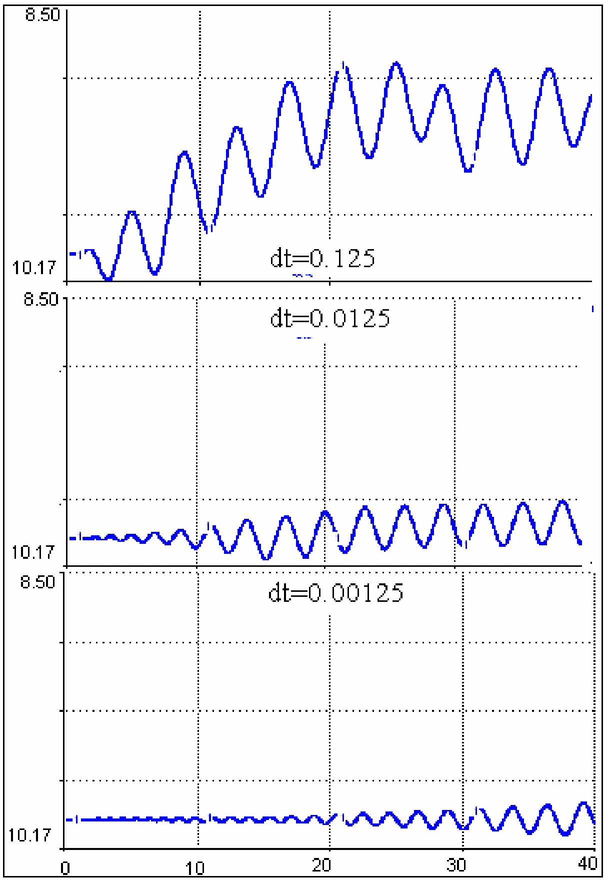



Figure 3.11. Results with Euler method for Heuristic 2

As seen in Figure 3.11, there are significant differences in behavior with different dt values. For the smallest three dt values, the equilibrium levels for depth are different than other runs. Starting with dt=0.0125, similar behaviors are observed where there are minor differences. Thus, we can conclude that, dt values smaller than 0.0125 is adequate if Euler integration method is used.

Differing than the runs with Euler integration method, there are not significant behavioral differences between runs when Runge-Kutta 4 integration method is utilized. As integration error decreases with Runge-Kutta 4, it is seen that most of the runs give consistent results but dt=0.125 (Figure 3.12). Thus we conclude that dt=0.05 is adequate for simulation experiments if Runge Kutta 4 integration method is used. Other results with decision heuristic 2 can be seen in Appendix B.2.

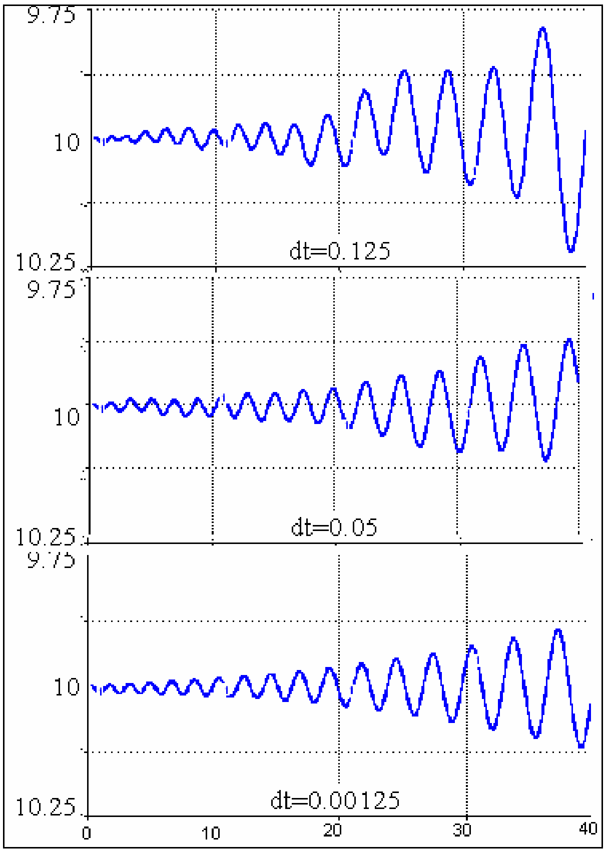



Figure 3.12. Results with Runge-Kutta4 method for Heuristic 2

### 3.4.3. Decision Heuristic 3 (Virtual Supply Line)

The third heuristic for dt validation is the application of virtual supply line. Yasarcan (Yasarcan, 2003) shows that first order material delay structure and indirect stock control with a secondary stock structure are equivalent. Additionally, supply line adjustment utilized for a more stable stock control policy in material delay structure can be applied to secondary stock control with some modifications. Secondary stock can be seen as a potential for primary stock and virtual supply line can be defined as secondary stock multiplied with secondary stock adjustment time.

When one more delay structure is added to both systems, indirect stock control with a third order stock structure and second order material delay structures become equivalent.

The supply line adjustment stock control policy applied in second order material delay can be applied to third order stock control with some modifications. Two virtual supply lines are defined for this purpose.

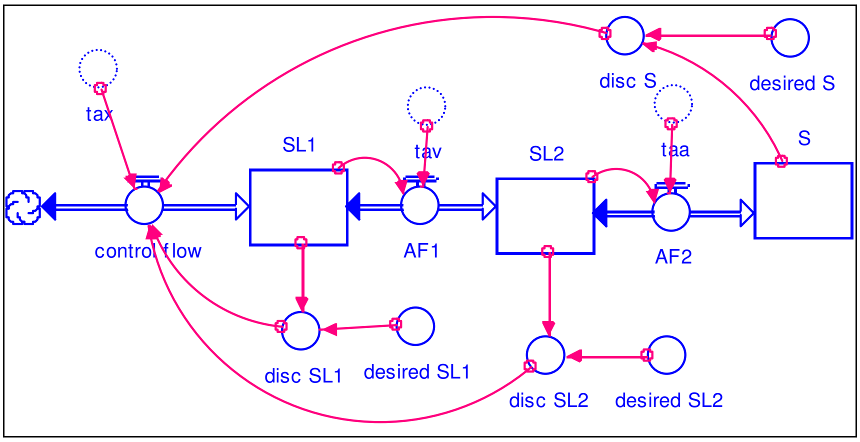



Figure 3.13. Second order material delay structure with supply line adjustment

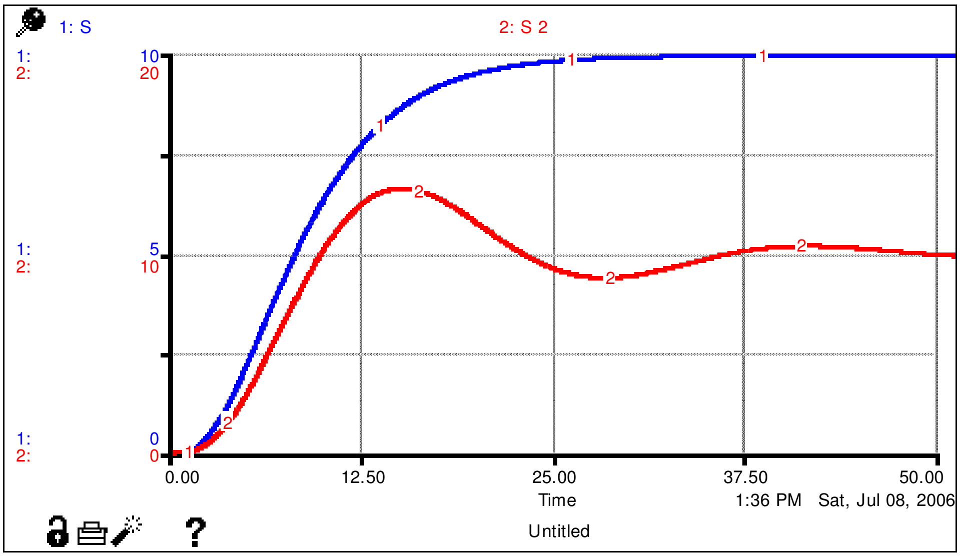



Figure 3.14. Behaviors with second order material delay structure, $t_{ax}$=4, $t_{av}$=3, $t_{aa}$=2

Stock flow structure of a second order material delay can be seen in Figure 3.13. When decisions are made only with comparing desired stock level and current stock level, oscillatory behavior may be observed. To prevent this unstable behavior, orders given previously but not received yet must be taken into account. The output behavior of stock variable S when supply line adjustment is not utilized can be seen in Figure 3.14 with label S2. As seen in the figure, damping oscillations are observed in the systems. On the other hand, when supply line adjustments are taken into consideration while making order decisions, the graph labeled as 1 in Figure 3.14 is obtained.

Differential equations defining the second order material delay structure can be seen in Equation (3.14). Stock flow structure of indirect stock control with third order stock can be seen in Figure 3.15. The rate of change of stock variable *x* equals to *v* and the rate of change of stock variable *v* equals to f(*x*,*v*,*a*). Order decision for the stock variable *a* is made depending on the value of stock variables *x* and *v*.

$$\dot{S} = SL2/t_{aa} \quad \dot{SL}2 = SL1/t_{av} - SL2/t_{aa} \tag{3.14.}$$

$$\dot{SL}1 = \frac{(S^* - S)}{t_{ax}} + \frac{(SL2^* - SL2)}{t_{ax}} + \frac{(SL1^* - SL1)}{t_{ax}} - \frac{SL1}{t_{av}}$$

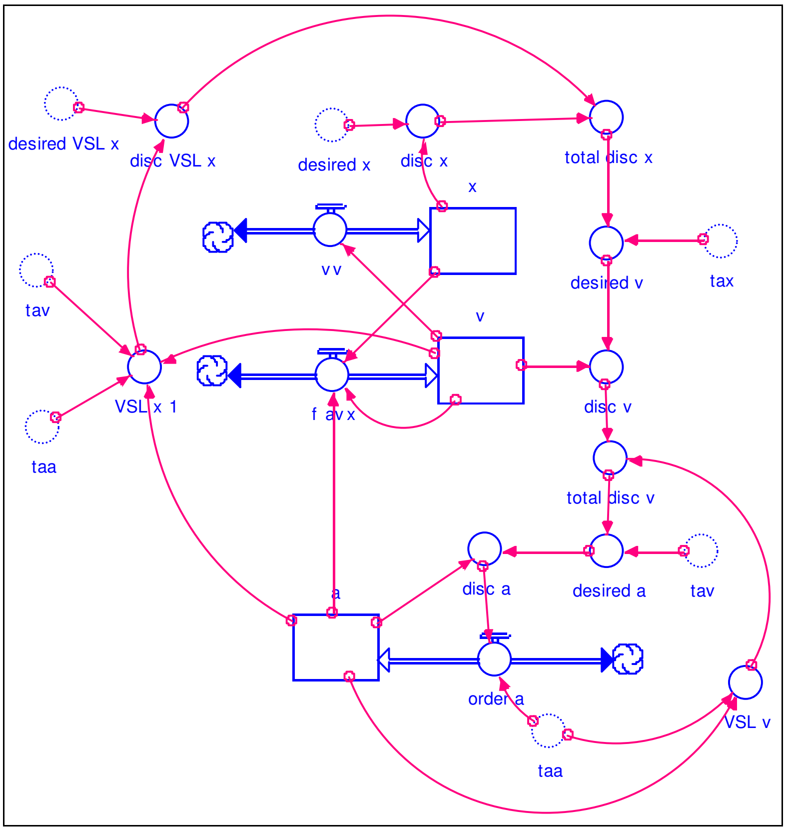



Figure 3.15. Stock-flow diagram of a third order indirect stock control structure

First, desired value of *x* is compared with the actual value of *x* and the difference will be divided by stock adjustment time for variable *x*. The value will be desired value of stock *v*. The difference between desired and actual values of *v* is further divided by stock adjustment time for *v* and desired f(*x,v,a*) and desired *a* is obtained. The same comparison is made between desired and actual values of *a* and the difference is divided by stock adjustment time for *a* and order decision is obtained for stock variable *a*.

In this order decision, potential stock level of *x* depending on the levels of *a* and *v*, which may also called as virtual supply line *x*, is not included. However, virtual supply line should be included to have more stable dynamic system. Thus, appropriate order decision function for the stock variable *a* is found by utilizing virtual supply line. Equation (3.15) defines indirect stock control with third order stock where $\dot{a}$ will be determined to make systems equivalent.

$$\begin{aligned} \dot{x} &= v \\ \dot{v} &= f(x,v,a) \\ \dot{a} &= h(x,v,a,t_{ax},t_{av},t_{aa}) \end{aligned} \qquad (3.15.)$$

Let x=S, then;

$$\begin{aligned} \dot{x} = \dot{S} &\Rightarrow v = SL2/t_{aa} \\ \dot{v} = S\dot{L}2/t_{aa} &\Rightarrow f(x,v,a) = (SL1/t_{av} - SL2/t_{aa})/t_{aa} \\ = (SL1/t_{av} - v)/t_{aa} &\Rightarrow SL1 = (f(x,v,a)*t_{aa} + v)*t_{av} \end{aligned} \qquad (3.15)$$

When we continue with differentiating both sides of the equation following equality holds:

$$\begin{aligned} S\dot{L}1 &= (\frac{\partial f}{\partial t} * t_{aa} + \dot{v}) * t_{av} \Rightarrow \\ \frac{(S^* - S)}{t_{ax}} + \frac{(SL2^* - SL2)}{t_{ax}} + \frac{(SL1^* - SL1)}{t_{ax}} - \frac{SL1}{t_{av}} \\ &= (\frac{\partial f}{\partial t} * t_{aa} + f) * t_{av} \end{aligned} \qquad (3.16)$$

$$\frac{\partial f}{\partial t} = \frac{\dfrac{\dfrac{(x^* - x) + (v^x * t_{aa} - v * t_{aa}) + ((f^* * t_{aa} + v^*) - (f * t_{aa} + v)) * t_{av}}{t_{ax}}}{t_{av}}}{t_{aa}} - \frac{\dfrac{(f * t_{aa} + v)}{t_{av}} - f}{t_{aa}} \qquad (3.17)$$

Since $\frac{\partial f}{\partial t} = \frac{\partial f}{\partial a} * \dot{a} + \frac{\partial f}{\partial v} * f + \frac{\partial f}{\partial x} * \dot{v}$, then $\dot{a}$ equals to Equation (3.18).

$$\dot{a} = \frac{\dfrac{\dfrac{\dfrac{(x^* - x) + (v^x * t_{aa} - v * t_{aa}) + ((f^* * t_{aa} + v^*) - (f * t_{aa} + v)) * t_{av}}{t_{ax}}}{t_{av}}}{t_{aa}}}{\partial f / \partial a} - \frac{\dfrac{\dfrac{(f * t_{aa} + v)}{t_{av}} - f}{t_{aa}} - \dfrac{\partial f}{\partial v} * f - \dfrac{\partial f}{\partial x} * \dot{v}}{\partial f / \partial a} \qquad (3.18)$$

When this rate of change value of *a* is used as the order policy for stock variable *a*, indirect stock control via third order stock and second order material delay structures become equivalent which means that in both structures stability will be provided. From the equation (3.18), virtual supply line *x* equals to $v*t_{aa}+(f*_{taa}+v)*t_{av}$ and virtual supply line of *v* equals to $f*t_{aa}$.

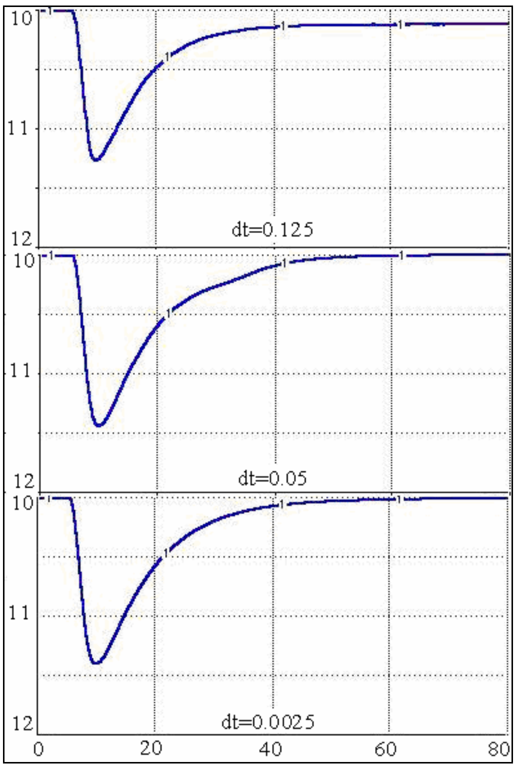



Figure 3.16. Typical results obtained with Euler method with Virtual Supply Line

Since virtual supply line is very effective in control, disturbance amount is increased to see differences between output behaviors. For disturbance Pulse=(air,5,0) function is utilized. Additionally, for air, velocity and depth stocks adjustment times 2, 3, and 5 seconds are utilized respectively.

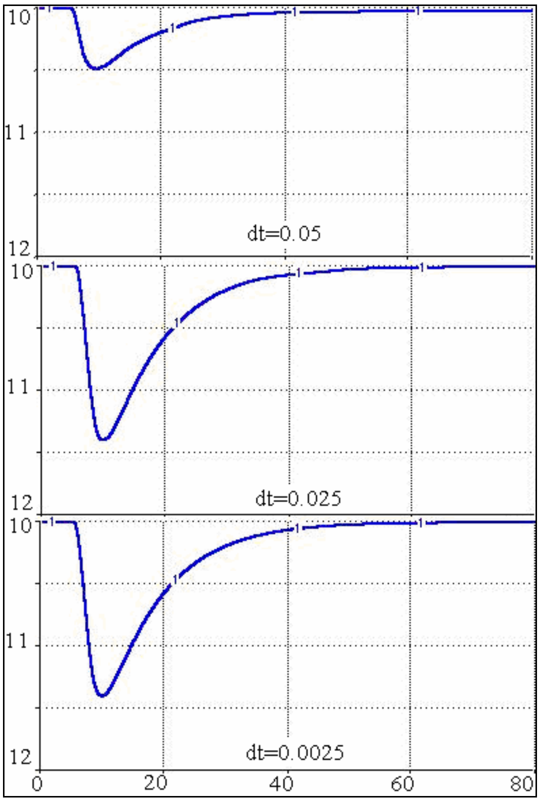



Figure 3.17. Results with Runge-Kutta 4 method with Virtual Supply Line

As the simulation runs are analyzed, it is seen than after disturbance system shows goal seeking behavior in all the runs. However, in the run with Euler integration method with dt=0.125, equilibrium level is different than 10 meters. So, it is concluded that when Euler integration method is used, dt should be at most 0.05. On the other hand, in Runge Kutta 4 runs when dt is taken as 0.05, minimum depth value differs from other runs which shows inadequate dt. Thus, for Runge Kutta 4 integration method, dt should be at most 0.025. Other output behaviors can be seen in Appendix B.3.

### 3.4.4. Verification with Real Decision Input

In deciding the appropriate dt value, real decision data are also used. In the game, where the real decision data are obtained, dt equals to 0.0125. So, the decision interval was originally 0.0125. The decision data are used to form a graphical input in the Stella simulation software. The simulation tool, Stella, has limited capacity for the data. Since its limit is 1600 data points, the first 18 seconds decision data are utilized for the pure verification purposes. Another way to utilize the data was entering the decision data at every 8 simulation intervals, in other words each 0.1 seconds. With this method, most of the experimental data can be utilized for longer simulation length. To create disturbance, the following function is used: if (time<0.249) then (1.20) else (0). Both models are run with Euler and Runge-Kutta 4 integration methods.

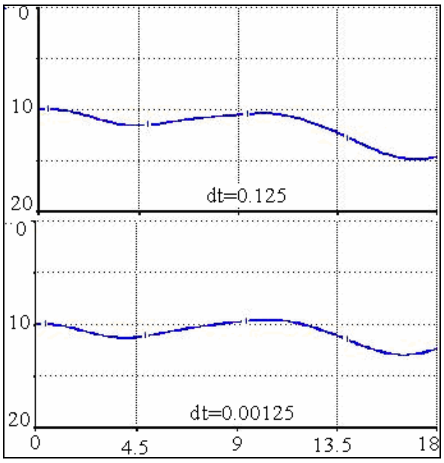



Figure 3.18. Results with Euler method: the first 18 seconds of real data

As mentioned previously, due to the limits of simulation tool, the first 18 seconds data are utilized for dt verification. In the graphical function, x-axis is divided into equal time intervals each has length of 0.0125 seconds. Discrete option is used for entering the data, by which only -1, 0 and 1 decisions are allowed. When dt is smaller than 0.0125, there is no problem. But if it is larger than 0.0125, player's decisions can not be appropriately used by the model. To clarify with an example, assume that player's initial decision is 0. At time t=0.0125, player decides to inflate for 1 second. In this situation when the model is simulated with dt=0.125, the inflating decision will not be made at time t=0.0125 but at t=0.125. This situation may result in big differences in behavior. All simulation results with different dt values seem to be consistent with Runge-Kutta 4 integration method, whereas with Euler integration method only dt=0.125 is not adequate (See Figure 3.18, Figure 3.19 and Appendix B.4). It would be more informative if simulation period is increased.

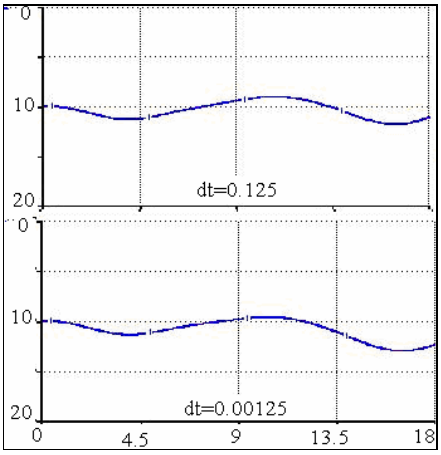



Figure 3.19. Results with Runge-Kutta 4 method: the first 18 seconds of real data

Due to the limits of the simulation tool, real data are smoothed to increase the length of simulation to 72 seconds, which can be enough to observe the behavior of the model and adequacy of dt values. For Euler Integration method, all dt values are seem to be appropriate but dt=0.125 (Figure 3.20 and Appendix B.4).

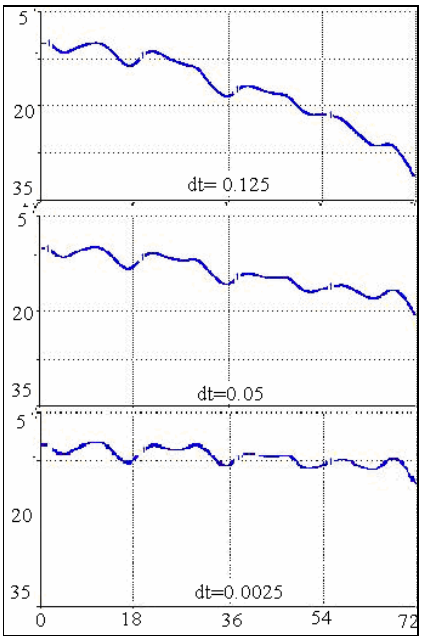



Figure 3.20. Results with Euler method: smoothed data

There is a significant difference between dt=0.125 and others. So, dt must be at most 0.05 for Euler integration method. When Runge-Kutta 4 integration method is utilized, significant differences between runs as integration interval is changed. When output behaviors are compared, it is observed that at dt = 0.025 there exists major differences (See Figure 3.21 and Appendix B.4). There are not significant differences between runs which are simulated with integration interval 0.0125, 0.005, 0.0025. We can safely conclude that integration interval must be smaller or equal to 0.0125.

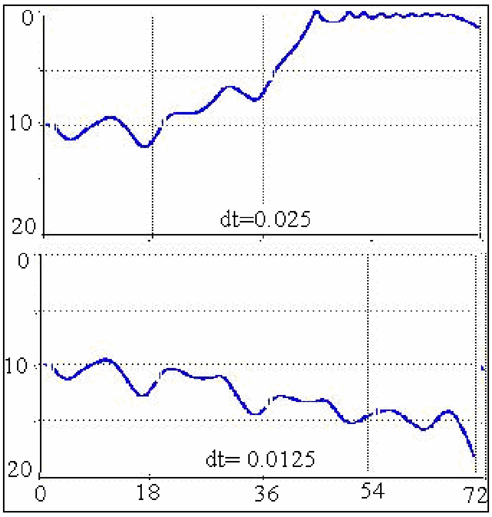



Figure 3.21. Results with Runge-Kutta4 method: smoothed data

### 3.4.5. Verification Conclusion

Based on verification results obtained in this section, dt=0.0125 is adequate if Runge-Kutta 4 or Euler integration method is used. Another decision criterion for appropriate dt value is the real time it takes to complete a simulation run which will be discussed in the next chapter. In conclusion, in all games, dt=0.01 value is used with Runge-Kutta 4 integration method.

## 3.5. Base Behavior of the Model

It is assumed that dynamics of the diving process is oscillatory and one of the objectives of this study is to analyze the reasons of this problematic behavior. In this part of the study, the model will be simulated with a given heuristic in different game settings.

The difference in the game settings will be due to material and information delays. Material delay is the result of the time required for air to pass the pipe. The material delay is modeled as continuous. The information delay is due the delays in equipment showing the depth of diver. Equipment can not show the depth data instantaneously; there may be small delays in reporting depth data. In one version of the game, information delay is used. It is also a continuous delay like material delay. There will be four different structures depending on the type of delay: No delay, Material delay, Information delay, Material and Information delay.

To run the model, air adjustment decision must be made. A stock adjustment heuristic is used to make the decision. In this heuristic, depth data is compared with desired depth value. The discrepancy is divided by depth adjustment time which results in desired velocity. The desired velocity data will be compared with velocity data. The discrepancy will be divided by the velocity adjustment time which results in desired acceleration. With the given acceleration, desired volume of air is found as in Equation (3.19), where $d^*$ and d are desired and actual depth values, $t_d$ and $t_v$ are stock adjustment times of depth and velocity variables, $\frac{d^* - d}{t_d}$ and v are desired and actual velocities and $\left(\frac{d^* - d}{t_d} - v\right)\Big/t_v$ is desired acceleration.

$$V^* = \frac{mass * \left(\frac{\left(\frac{d^* - d}{t_d} - v\right)}{t_v}\right) - mass * g - F_{drag}}{density * g} \tag{3.19}$$

If desired volume is larger than actual volume, then inflating decision is made, if it is smaller, deflating decision is made. If desired value equals to actual volume, then neither inflating nor deflating decision is made.

$$f = \begin{cases} 1 & V^* > V \\ -1 & V^* < V \\ 0 & V^* = V \end{cases} \tag{3.20}$$

The decision heuristic is very similar to decision heuristic 2 used in dt verification section, where decision is made based on discrepancy between desired and actual velocities. Here, desired air is calculated and air adjustment decision is made based on the discrepancy between desired and actual air stocks.

First, depth and velocity adjustment times will be decided and then the model will be run with different air flow volumes, delay settings and delay times.

### 3.5.1. Base Runs With Different Depth and Velocity Adjustment Times

The model is run with 1 sec, 5 sec and 25 sec depth and velocity adjustment times. There is neither material delay nor information delay in this first case. Air flow volume is 4 liters/sec. Runge-Kutta 4 is used as integration method and 0.005 is used as dt

In Figure 3.22, decision process and the model structure, which are simplified for clarity, The ratio between depth and velocity adjustment times is very influential on behavior of the model (See Figure 3.23). As the ratio gets smaller, oscillations are observed. On the other hand, if the ratio increases, the behavior turns out to be goal seeking. In the remaining trials depth adjustment time is taken to be 5 seconds whereas velocity adjustment time is taken to be 20 seconds.

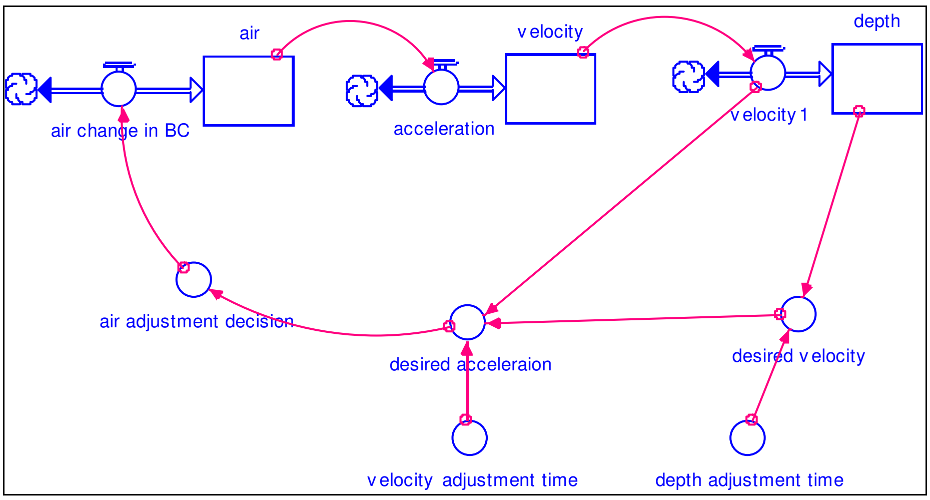



Figure 3.22. Model structure without delay

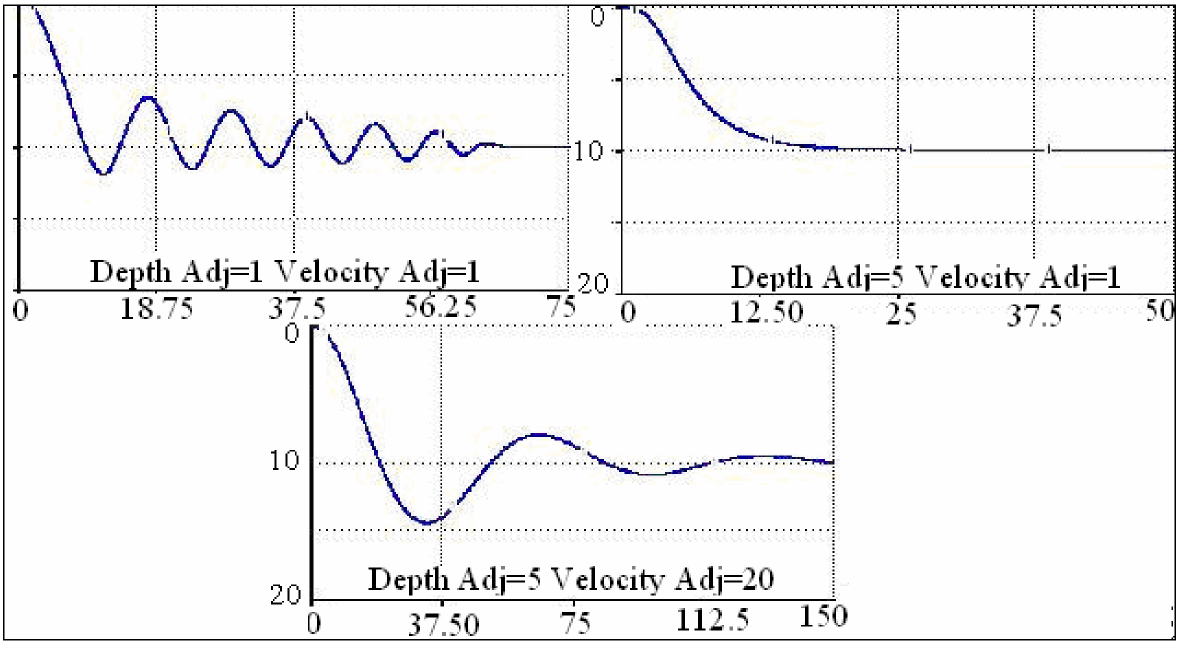



Figure 3.23. Simulation results with different depth and velocity adjustment times

### 3.5.2. Effect of Flow Volume

It is thought that flow volume is effective on the control of the depth variable. Flow volume can be seen as the power of the control tool. If the tool is powerful, it is easier to control the system. In that respect, one can think that, if flow volume increases, system will be more stable. The system is initially at equilibrium (10 meters) and pulse function is used to produce the disturbance. At time t=0, all air is deflated with the given pulse function (PULSE(air,0,0)).

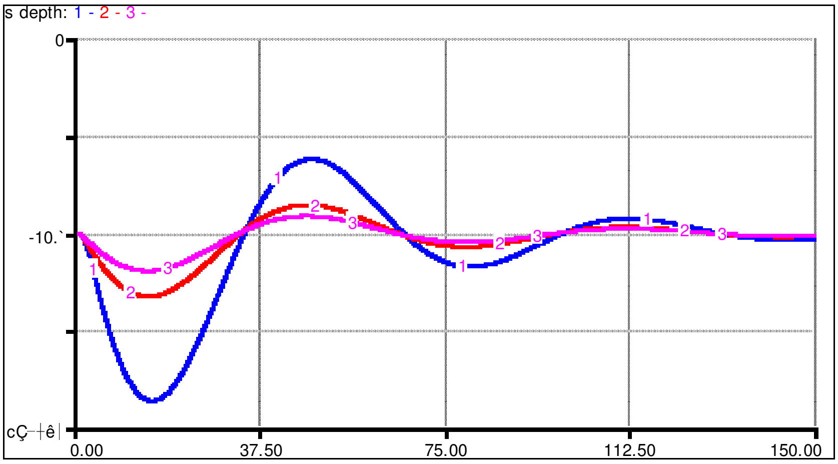



Figure 3.24. Simulation results with different air flow volumes (1: 1 lt/sec, 2: 4 lt/sec, 3: 7 lt/sec)

The increase in the flow volume from 1 to 4 (or to 7) resulted in the decrease of the amplitude of oscillations (See Figure 3.24). If we analyze the effect of an increase from 4 to 7, we see that the amplitude of oscillations is somewhat decreased.

### 3.5.3. Effect of Material Delay

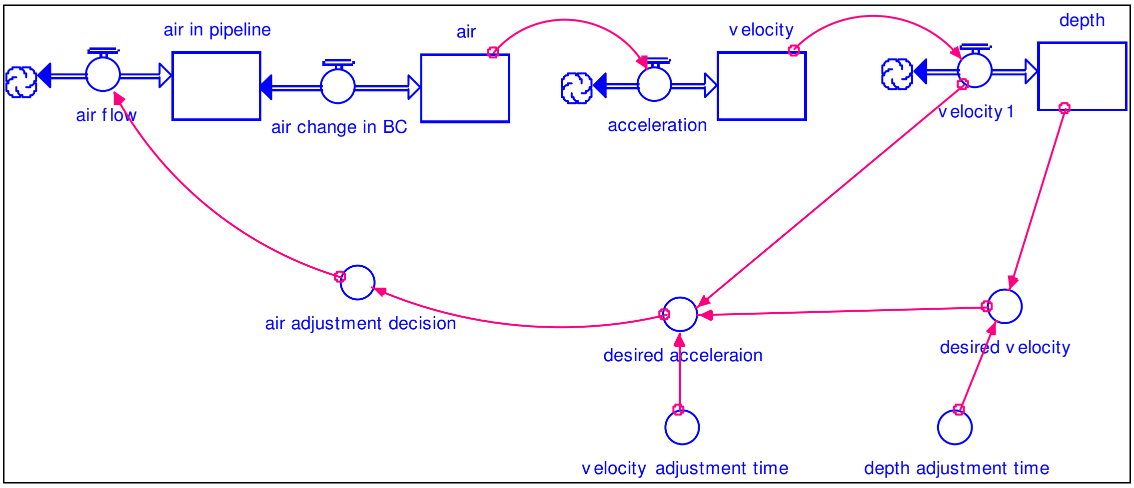



Figure 3.25. Model structure with material delay

There is a physical material delay in air stock. This represents the time that it takes air flow from tube to BC. Throughout the simulation runs, flow volume is taken to be 4 liters/sec. At time t=0, the system is at equilibrium (10 meters) and all air is deflated with the pulse function (PULSE(air,0,0)). In Figure 3.25, one can see the model structure used in the analysis.

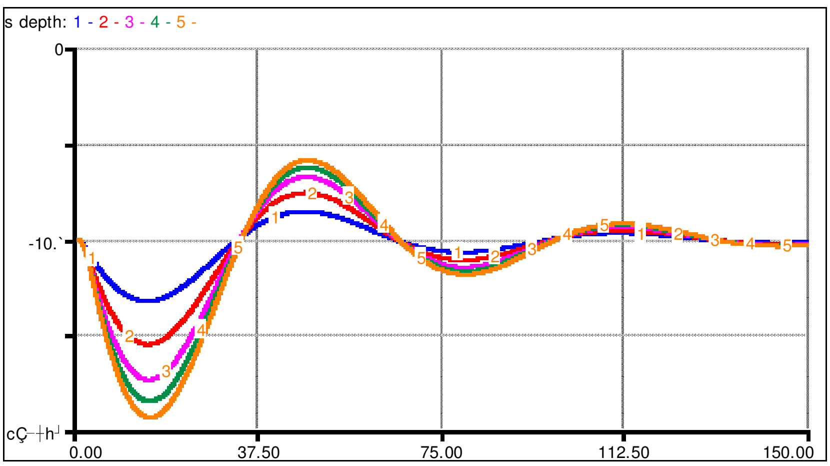



Figure 3.26. Simulation results with different delay times (1:0, 2:1, 3:3, 4:5, 5:7 sec)

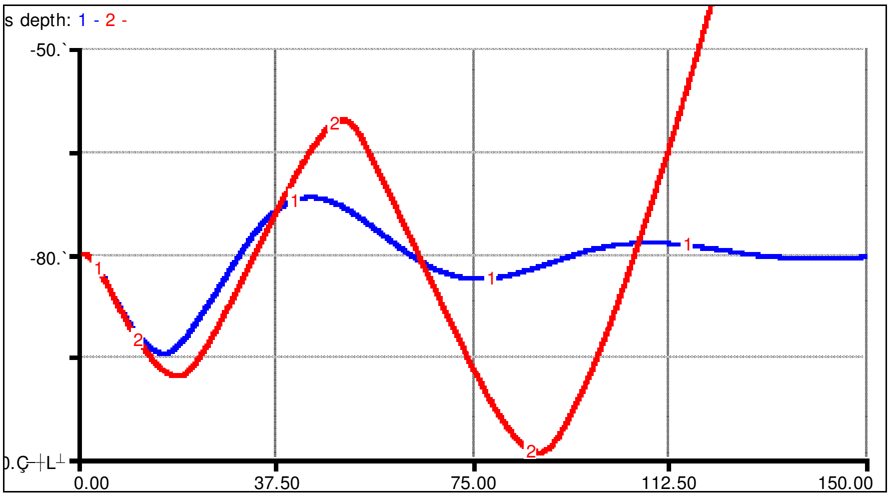



Figure 3.27. Simulation results with different delay times (1:40 sec, 2:60 sec)

The output behaviors obtained with different material delay times can be seen in Figure 3.26 and Figure 3.27. As we look the general behavior of the system, we observe damping oscillations. The amplitude of the oscillations increases, as the material delay increases. Extreme runs are also made with high material delay. As seen in Figure 3.27, with 40 seconds material delay, damping oscillations are observed whereas when delay is increased to 60 seconds, growing oscillations are observed. In these two cases, initial and desired depth values are changed to 80 meters, so that behavior of the model can be fully observed.

Since we assume that decision makers will have depth information delay, it is more important to analyze the effect of material delay when the information delay is present.

### 3.5.4. Effect of Depth Information Delay

As mentioned above, there may be information delay due to equipment. In these trails, effect of depth perception on the output behavior of the model is evaluated. Note that in general, velocity data can not be observed directly. It can be perceived via the slope of the depth graph. This slope equals to the derivative of the depth variable. Previously, depth data could be observed instantaneously and the slope of the depth was equal to the velocity. But now, depth is perceived after some delay and the velocity used in making air adjustment decision is found from the slope of perceived depth. The derivative of perceived depth equals to the velocity perceived, so that when there is a delay in depth perception, there is also an implicit delay in velocity perception.

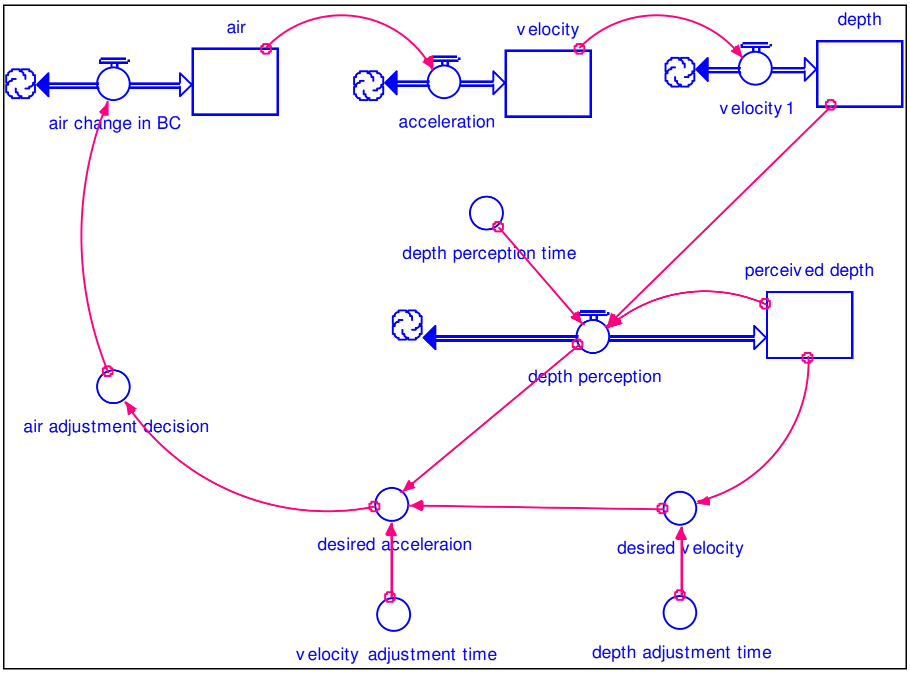



Figure 3.28. Model structure with depth information delay

To sum up, desired velocity is found by dividing the discrepancy between desired depth and perceived depth by depth adjustment time. And, desired acceleration is found dividing the discrepancy between desired velocity and perceived velocity, which equals to the slope of depth graph (depth perception), by velocity adjustment time.

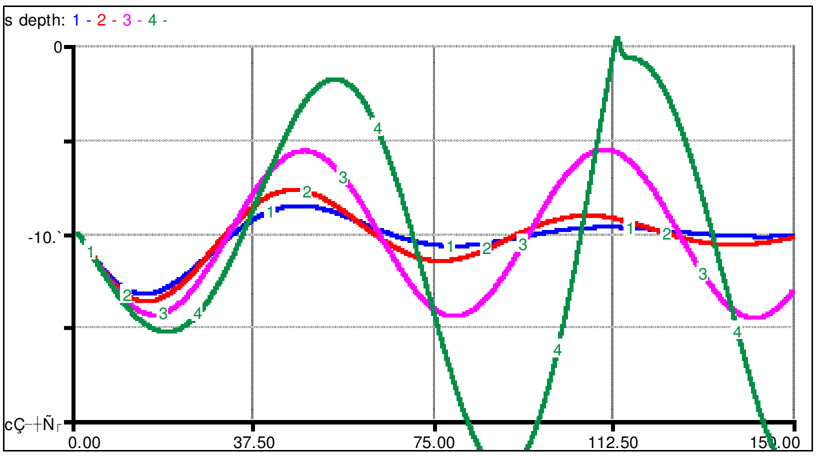



Figure 3.29. Simulation results with different depth information delays (1:0 sec, 2:2 sec, 3:5 sec, 4:10 sec)

Output behaviors with different depth information delay times can be seen in Figure 3.29. In the first trial, depth information delay is 0, base case. It is 2 seconds, 5 seconds and 10 seconds in the second, third and fourth trials respectively. In the first two trials, we observe damping oscillations. Third run can be classified as constant amplitude oscillation but in the last run, the behavior turns out to be growing oscillations.

### 3.5.5. Effect of Material Delay and Information Delay

There may be material delay due to pipe and information delay due to equipment. It is important to evaluate the effect of these two delays when both of them exist. The structure of the model can be analyzed in Figure 3.30.

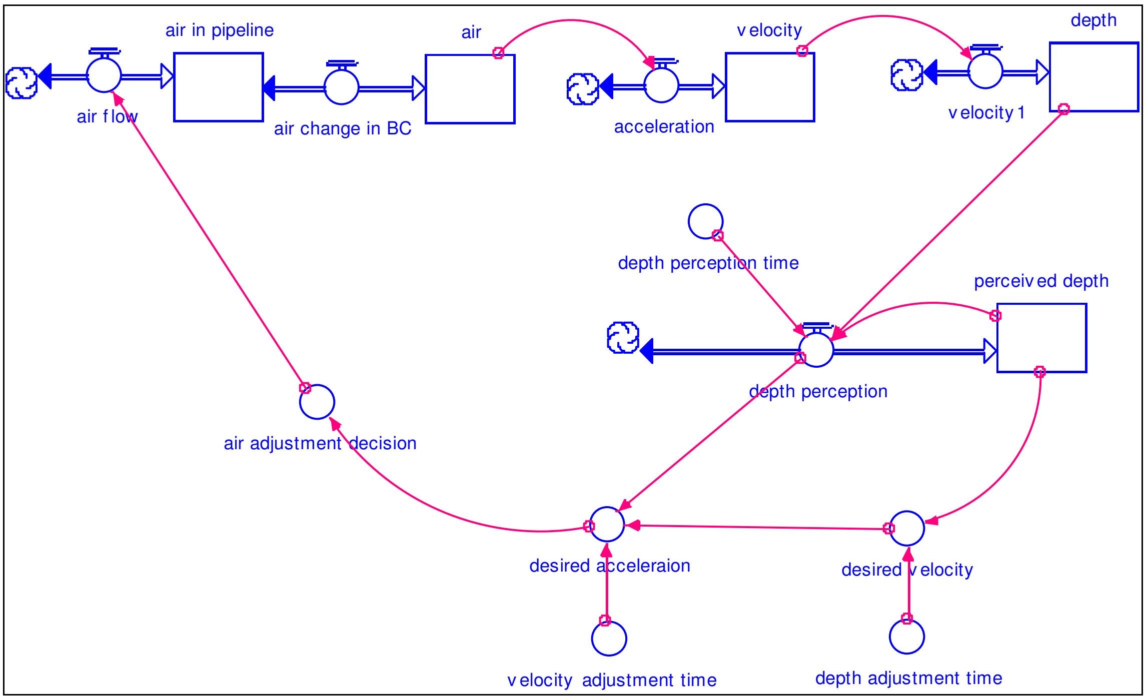



Figure 3.30. Model structure when both material and information delay exist

In Figure 3.31, results can be observed when depth information delay is fixed at 2 seconds and material delay is varied. As the material delay is increased, it is observed that behavior of the system remains the same, damping oscillations. But, the amplitude of the oscillations increases when material delay time is increased.

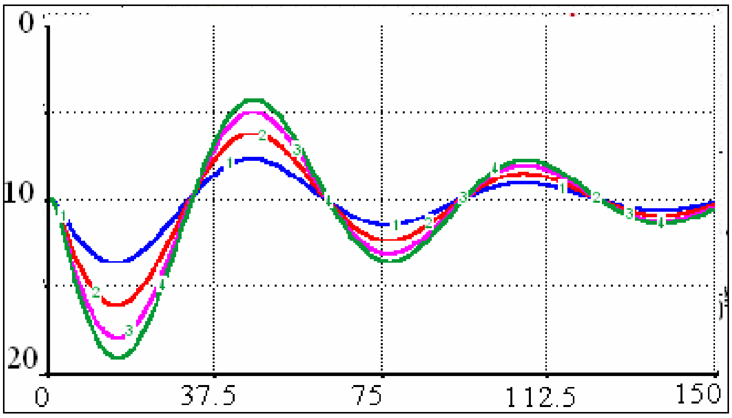



Figure 3.31. Results with depth information delay of 2 seconds and different material delays (1:0 sec, 2:1 sec, 3:3 sec, 4:5 sec)

The runs in Figure 3.32 and Figure 3.33 are obtained to determine whether material delay time changes the behavior of the system. In the 1st runs there is no material delay whereas depth information delay equals to 5 seconds and 7 seconds. Fixing depth information delay, material delay is increased. As the material delay increases, the amplitude of the oscillations increases but the behavior of the system does not change when depth information delay equals to 5 seconds. On the other hand if the depth information delay is fixed at 7 seconds, growing oscillations are observed. Similar to the case with depth information delay 5 seconds, output behavior of the system does not change with increasing material delay, but the amplitude of the oscillations increases.

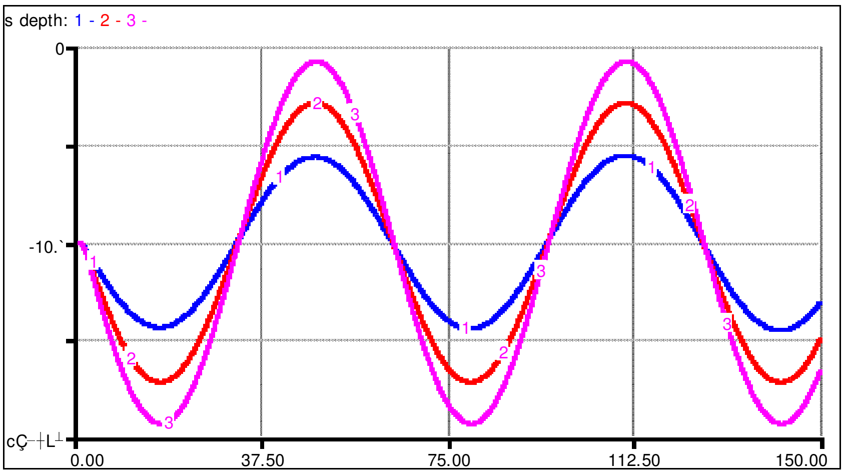



Figure 3.32. Results with depth information delay of 5 seconds and different material delays (1:0 sec, 2:1 sec, 3:3 sec)

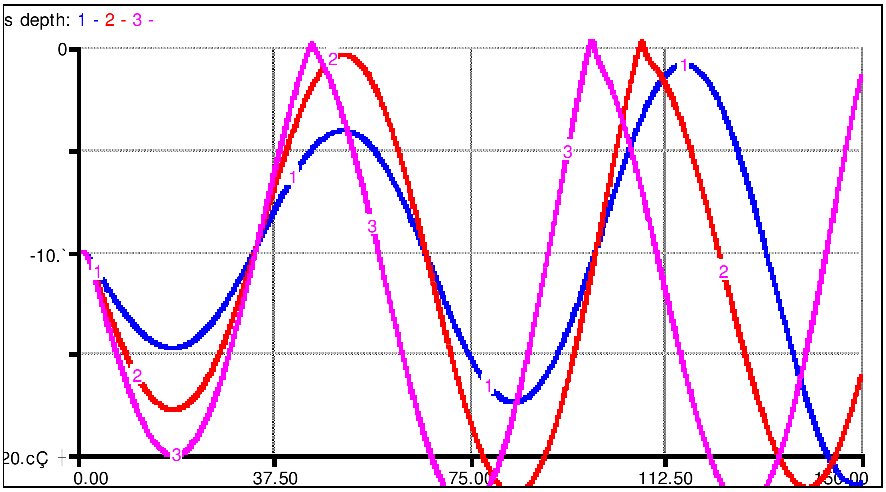



Figure 3.33. Results with depth information delay of 7 seconds and different material delays (1:0 sec, 2:1 sec, 3:3 sec)

# 4. INTERACTIVE SIMULATION GAME (ScubaSim)

After validating the model, game version is formed to analyze the effects of game speed, air flow volume, length of delays and previously owned experienced on subject's performance. Mostly graduate students and engineering students played the game.

## 4.1. Game Interface

After the validation of scuba diving model, it is converted to a game where subjects make air adjustment decision to stabilize at desired depth. In the opening window, subjects may explore the model, have some background about diving and game or directly play the game (See Figure 4.1). The briefing prepared for ScubaSim simulator is also accessible via background buttons.

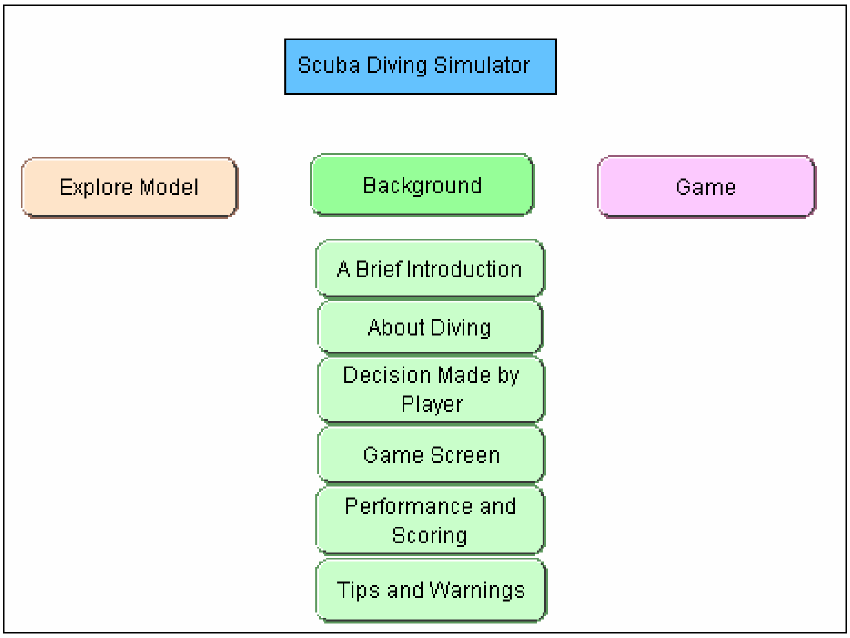



Figure 4.1. Snapshot of the opening window of ScubaSim simulator

If subject wants to explore the relationships between variables, he can use "explore model" button. Here, one can easily see basic relationships and the graph will be helpful in getting insight about the dynamics of diving system.

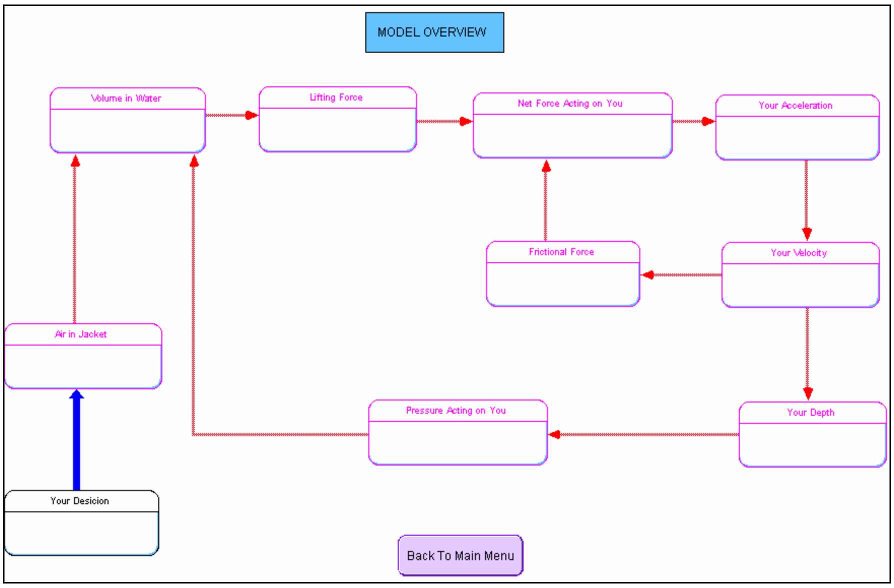



Figure 4.2. Snapshot of model overview window of ScubaSim simulator

During the game, subjects will observe depth from depth-time graph as seen in Figure 4.3. They are also expected to perceive velocity from the slope of the depth-time graph. The decisions made by subject can be entered via the slider just below the depth-time graph. Once the run button is clicked, simulation will start and will not stop until simulation is finished at t=90 seconds, except for games with pause option.

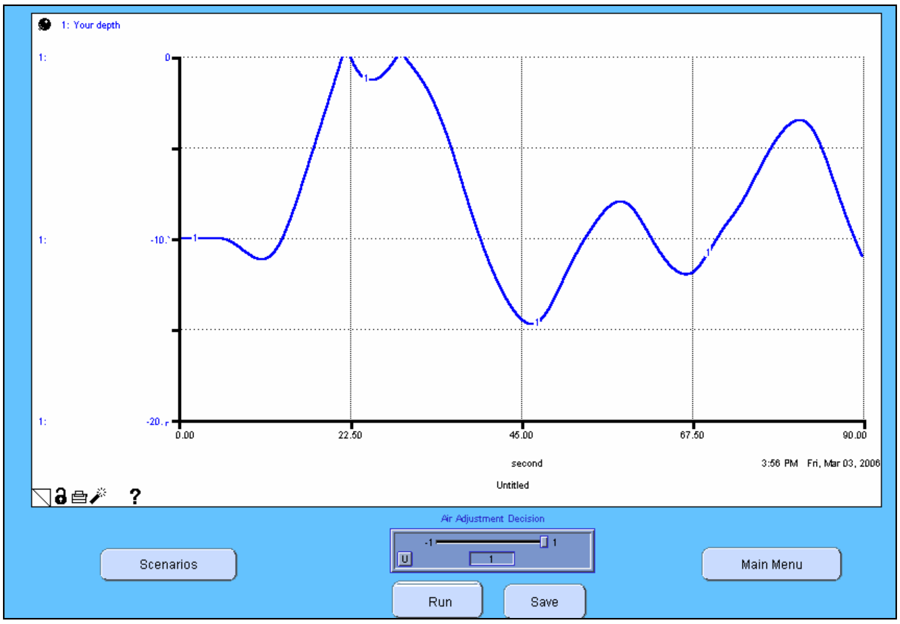



Figure 4.3. A typical example of game screen (at the end of game)

Air adjustment decision is modeled to be discrete, -1, 0 and +1. In the left part of the slider, it is (-1), in the right part it is (1) whereas in the middle parts it is 0. Slider at -1 means deflating at a constant speed, +1 means inflating at a constant speed and 0 means no air flow into or from BC.

### 4.2. Experimental Procedure

Subjects volunteered to participate in the experiment. Depending on game type and relative success in the game, they are paid between 5 YTL and 15 YTL. The playing date of each subject is scheduled beforehand and game briefing is given to the subject. There are minor differences between games and corresponding briefings. As a representative example, briefing for subjects playing Latin square experiments can be read in Appendix C.1.

For each subject, the specific order of games to be played is prepared. For instance, in Latin square design, a subject plays 8 different games in completely different sequence from other subjects' game sequences. To preclude any mistake in the order and structure of the games, they are arranged by experimenter in advance. Additionally, a document is prepared showing properties of the games such as game speed, presence of delays and air flow volume.

For each subject, the following procedure is applied. Firstly, the subject reads the briefing. Then, experimenter answers questions of subject and clarifies the points that are not well understood by subject. The process continues with explaining game interface and decision tool to subject. Since it is not easy to control slider, subject is given time to become experienced in using slider.

Before the games used in data analysis, each subject plays the pilot version of the game. In Latin square experiments, slow pace, no delay and high flow volume game is presented as the pilot version. On the other hand, in repeated measures experiments, a mild version of the game is presented. For instance, in material delay game, subjects play the game with material delay equals to 0.25 seconds whereas in real game, it is 0.5 seconds.

Additionally, flow volume was 1 liter/sec in pilot version whereas it is 3 liters/sec in normal games.

After the pilot version is played and subjects feel comfortable with the game, they start to play experimental games. Just after the first trial, a questionnaire is applied. The questionnaire can be seen in Appendix C.2. After completing the questionnaire, subjects play the remaining trials. At the end of the last trial, similar questionnaire is applied to see whether there are differences in answers between two questionnaires.

As mentioned previously, it is not easy to use the slider tool and to key in the decisions made. There may be errors such that subject may have decided to inflate air but s/he may enter -1 with slider which in fact deflates air. To eliminate these problems, subjects can call experimenter whenever they made such an error and the trial is replayed from the beginning.

## 4.3. Effects Investigated

### 4.3.1. Effect of Game Speed

In the literature, it is hypothesized that as the speed of game increases, performance of the subject decreases. However experimental results do not completely support this hypothesis (Gonzalez, 2004 and Grossler, 1995). Furthermore, the effect of game speed on learning is also analyzed by Gonzalez and (practice) x (game speed) interaction effect is found to be effective on performance (Gonzalez, 2004). In other words, performance improvement in slow games is found to be higher than the performance improvement in fast condition games.

Now, comparison between ScubaSim and simulators/micro worlds used in earlier studies will be presented with respect to decision interval and game length. To start with predator-prey model of Grosser, it is stated that in faster game, simulation step lasts 0.8 seconds, whereas in slower game it is 1.6 seconds. The experimental results show that subjects in fast game are more successful than the subjects in slow game. However, the difference is not statistically significant (Grosser, 1999). Continuing with firefighting micro world of Brehmer, it is stated that game screen is updated every 20 seconds which implicitly shows that decision interval is 20 seconds (Brehmer, 1990 and 1995). Lastly, in Water Purification Plant of Gonzalez, slow game takes 24 minutes whereas fast game takes 8 minutes to complete, however, length of decision interval is not mentioned.

In ScubaSim, simulation length is 90 seconds but it takes 143 actual seconds in fast game and 290 seconds in slow game to complete. At each dt=0.01, subjects may change their decisions. Additionally, in one version, subjects have opportunity to “pause” the game to think about the process without time pressure.

Subjects need time to observe output variables, make a decision with these output variables and enter the decision made. Additionally, in the learning process they need additional time to form and update mental models they used. In stock control games, decision intervals are usually unlimited. However, there are critiques about the absence of time pressure which is thought to be effective in reality. In scuba diving, the process is continuous and there is always time pressure. Thus, the decision process should be modeled as time continuous in the game.

Due to the mentioned characteristics, it is a good hypothesis to test the effect of time pressure on performance. There are mainly two types of games with different time pressure, slow pace and fast pace. Additionally, in one version of the games, subjects have an option to pause the game.

#### 4.3.2. Effect of Air Flow Volume

Another factor that is tested in ScubaSim is air flow volume. In the game, subjects make inflating/deflating decision which is a binary variable. In Latin Square experiments, in half of the games, the volume of inflated/deflated air per unit time is low, whereas in other half it is high.

The air flow volume is selected for investigation because its effect is not obvious. Air flow volume can be seen as control power. When the flow volume is high, the control tool is more powerful. The time needed to change the behavior of the system is relatively short compared to low air flow volume. On the other hand, the amount of air change may be much higher than the desired volume change and it might not be perceived before destructive effects are seen. High air flow volume is a powerful control tool, but subjects should be able to control the power of the tool.

On the other hand, in the low air flow games, time required to make desired volume change is relatively long. In such a longer period of time, system state may change significantly and trial may be completed with poor performance. On the other hand, if flow volume is low, difference between desired and actual volume change is expected to be smaller compared to high air flow volume.

After deciding to test the effect of air flow volume on performance, the flow volumes for low and high levels must be chosen. For low and air flow volume games, 1 lit/sec and 3 lit/sec are used in simulation runs respectively. The low level is high enough to control the system and the high one is low enough to prevent unrealistic volume change.

Another factor that must be mentioned about air flow volume is its interaction effect with game speed. To explain it with an example: Assume that the subject makes inflating decision for 1 real second. In slow game, 1 real second corresponds to 0.31 simulation seconds and in fast game it corresponds to 0.64 simulation seconds. Inflating air for 1 real second corresponds to 0.31 liters change in volume in slow game and 0.64 liters in fast game with low air flow, 0.93 liters in slow game and 1.92 liters in fast game with high air flow. Subjects should able to infer the difference between simulation time and real time to be successful in the game.

### 4.3.3. Effects of Information and Material Delays

The effects of material and information delays are widely studied (Aybat *et al.,* 2003, Brehmer, 1990 and 1995, Diehl and Sterman, 1995, Sterman 1989). Studies show that subjects' performances become worse when there is delay; information or material. People are not able to recognize delays or take into account the effects of delays. For instance, they do not utilize supply line (previously ordered but not yet received stock) information when giving new orders. This behavior results in oscillations and under-control of systems.

It is decided to evaluate the effects of material and information delay in a real-time dynamic decision environment. In diving process, there may be delays in perceiving depth. To model this, a first order exponential information delay structure is used with 0.5 seconds delay length (See Figure 4.4).

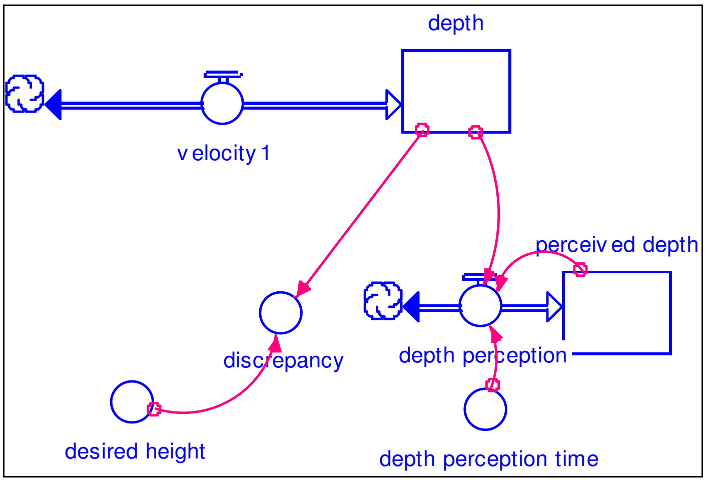



Figure 4.4. Information delay structure used in ScubaSim

Additionally, there may be material delays due to flow of air through tubes. This delay is modeled as a first order exponential material delay with 0.5 seconds delay length (See Figure 4.5).

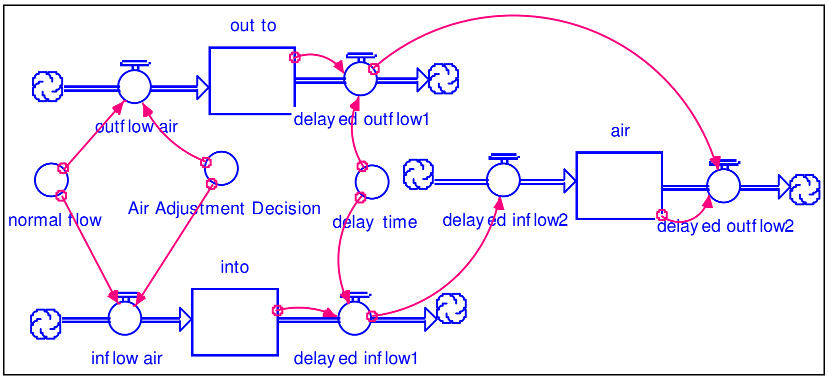



Figure 4.5. Material delay structure used in ScubaSim

In Latin square experiments, both delays are present in half of the games whereas in the other half, none of the delays is present. Since the effect of delays on performance is found to be very significant, in repeated measures experimental design, material and information delays are added to basic model separately to evaluate the effect of each delay individually.

The existence and length information of delays is given to subjects at the beginning of each trial. Subjects may form an appropriate strategy to cope with delays with the help of information.

In ScubaSim, subjects use depth-time graph to make inflating/deflating decisions. The velocity of diver can be perceived from the slope of the graph. When information delay is added to model, subjects also experience an indirect information delay in perceiving velocity.

Differential equations defining the stock control with secondary stock with information delay in primary stock can be seen in Equation (4.1), where *x* is primary stock, *y* is perceived value of primary stock after an information delay and *v* is the value of secondary stock. Now, it will be shown that perception rate which is equals to (*x*-*y*)/D equals the value of velocity perceived with an information delay D.

$$\begin{gathered} \dot{x} = v \\ \dot{y} = \frac{(x - y)}{D} \\ \ddot{y} = \frac{(\dot{x} - \dot{y})}{D} = \frac{(v - \dot{y})}{D} \end{gathered} \tag{4.1}$$

If we change variables $\dot{y} = z$ and $\ddot{y} = \dot{z}$, then previous equation becomes $\dot{z} = (v - z)/D$ which shows that z is perceived value of v after an exponential delay D. Thus, in ScubaSim as the depth values are observed after delay and velocity is perceived from the same graph, the velocity data is also perceived after the same information delay.

### 4.3.4. Effect of Scuba Diving Experience

Although the aim of this study is not modeling the diving process but to evaluate effect of game speed, air flow volume and delays on subject's performance, it is interesting to test the hypothesis that “subjects having prior scuba diving experience will be more successful than subjects who have no real experience”. Subjects with experience will probably have initial mental models which have been formed during real diving. On the other hand, their decision processes are somewhat intrinsic. They may decide inflating/deflating decision with feeling the movement of water. It is not possible to make subjects’ feel the flow of water in ScubaSim. In summary, there are significant differences between ScubaSim and real scuba diving. Subjects having scuba diving experience may even perform worse in ScubaSim due to the differences between models they have in their minds and the model used in the game.

For this reason, in the first experimental setting, half of the subjects are chosen to be scuba divers. Since the effect of being a scuba diver and the effect of game order is confounded, it is not possible to determine the effect of being a scuba diver. So, in the second game setting, scuba divers and non scuba divers play the same games to evaluate the effect of scuba diving experience.

## 4.4. Modeling the Environment and Behavior of Subjects

In this section, subjects’ decision process will be modeled with human perception. Human perception may be in the form of depth perception and velocity perception. In Section 3.5, velocity data is perceived from the slope of the depth graph. It is assumed that the velocity can be observed clearly and instantaneously. But in reality, it is not the case. Although the graph can be seen continuously, there will be delays in perceiving depth and velocity. For this reason, these two perception delays are introduced to the structure when subjects’ decision process is analyzed.

### 4.4.1. No Delays in the System Structure

The structure shown in Figure 4.6 assumes no delays in the diving system equipment. Subjects observe the depth variable from depth-time graph. There may be a perception delay due to processing of the depth data. Additionally, there may be a delay in perceiving the velocity. This data will be observed from the slope of the depth graph. The Figure 4.6 represents the situation where there is no delay in model structure. The two perception delays in the diagram merely represent the perception delays of subjects. When there is additional material and/or information delay, then the modeling process will be more complicated.

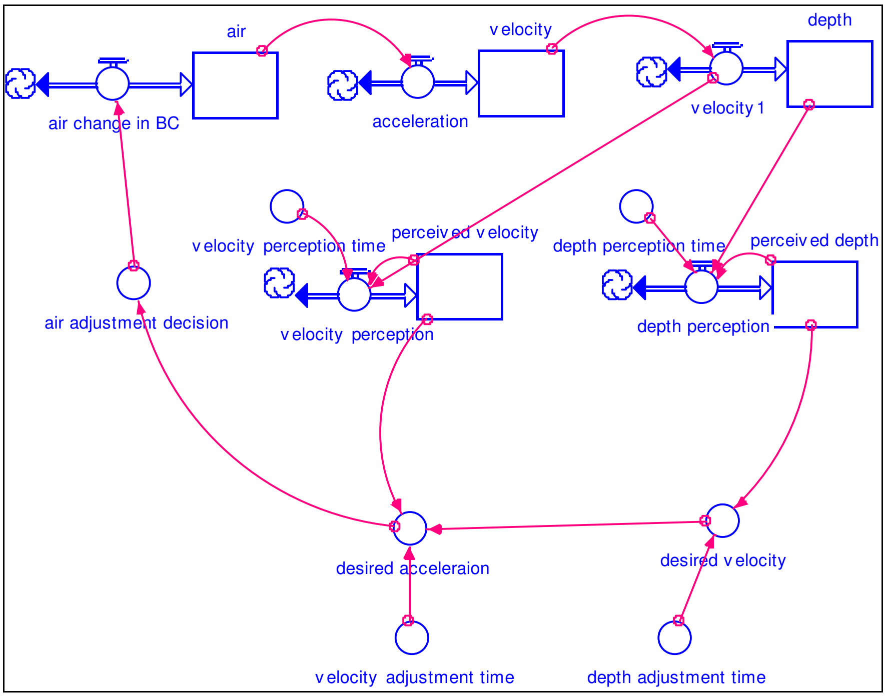



Figure 4.6. Structure of the subjects' decision process: no delay in environment

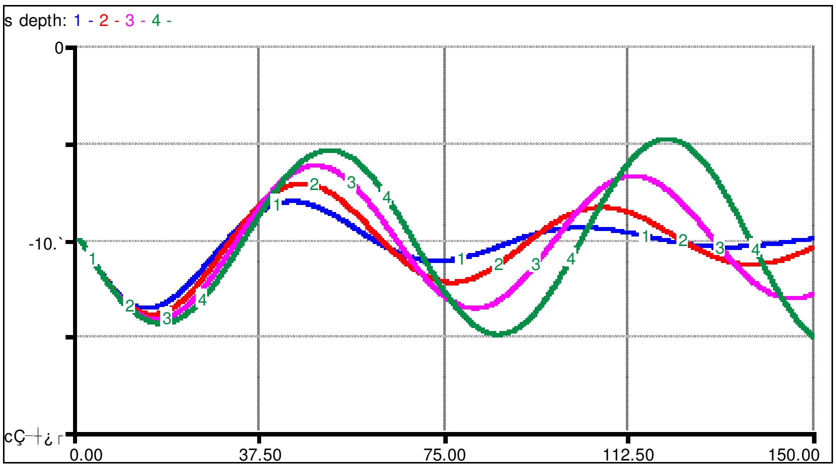



Figure 4.7. Simulation results with velocity perception is 3 sec and depth perception is varied (1:1 sec, 2:3 sec, 3:5 sec and 4:7 sec): no delay in environment

Delays due to depth and velocity perceptions result in similar behaviors. As seen in Figure 4.7, damping oscillations are changed to growing oscillations as depth perception time is increased and velocity perception time is fixed at 3 seconds. When velocity perception time increases, amplitude of the oscillations is increased and periods of the oscillations are decreased (See Figure 4.8). On the other hand when depth perception time increases, both amplitude and period of the oscillations are increased.

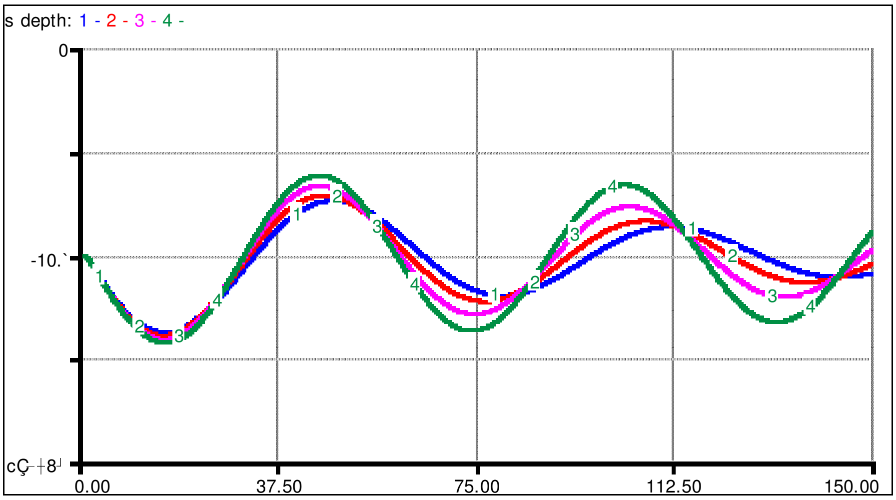



Figure 4.8. Results with depth perception equals to 3 sec and velocity perception is varied (1:1 sec, 2:3 sec, 3:5 sec and 4:7 sec): no delay in environment

### 4.4.2. Information Delay Exists

One type of the games that will be played contains depth information delay. In the game, depth information delay will be 0.5 seconds long, whereas in this analysis 1 second depth information delay is used. The corresponding decision making structure may be modeled as in Figure 4.9.

In the game, as mentioned before, there is a depth information delay lasting 0.5 seconds which is represented by perceived depth1 stock. This value can be observed from depth-time graph however there is no way to observe real depth value. Additionally, subjects can have delays in perceiving depth data from graph. Thus, to model the subjects' decision making, depth perception delay is used. Additionally, velocity will be perceived with a delay from depth graph. Velocity perception time and depth perception time2 will be different for different subjects but depth perception time1 will remain the same; 1 second.

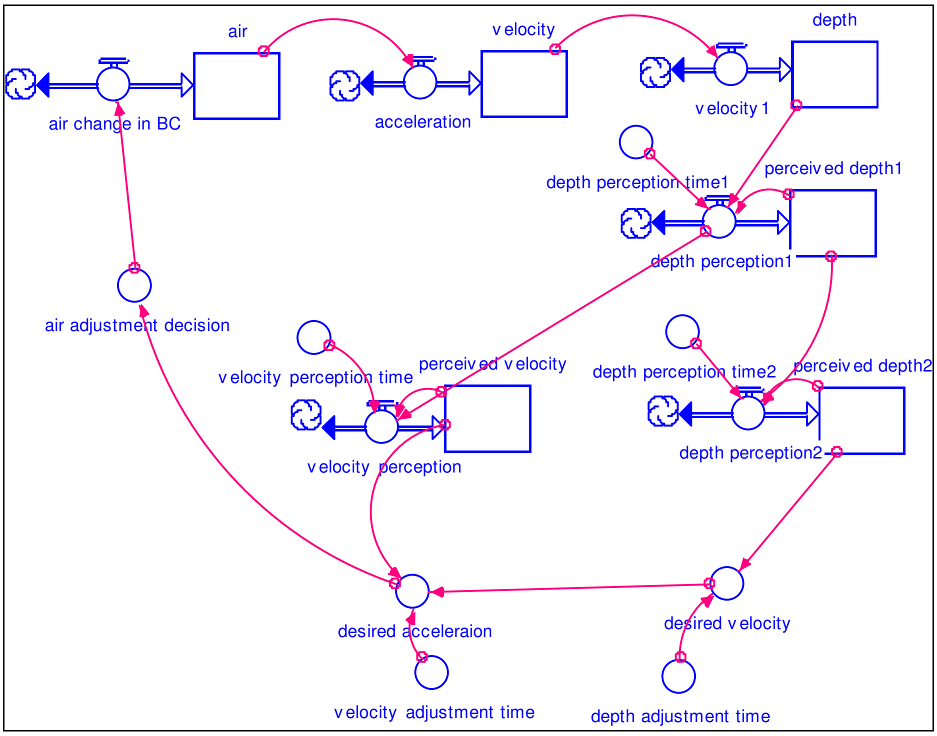



Figure 4.9. Structure of the subjects' decision process: depth information delay exists

When there is already a depth information delay, due to equipment, then it is harder to control the system. Both velocity perception and depth perception deteriorate the controllability of the system in similar ways. Damping oscillations turns to growing oscillations as perception delay increases (See Figure 4.10 and Figure 4.11).

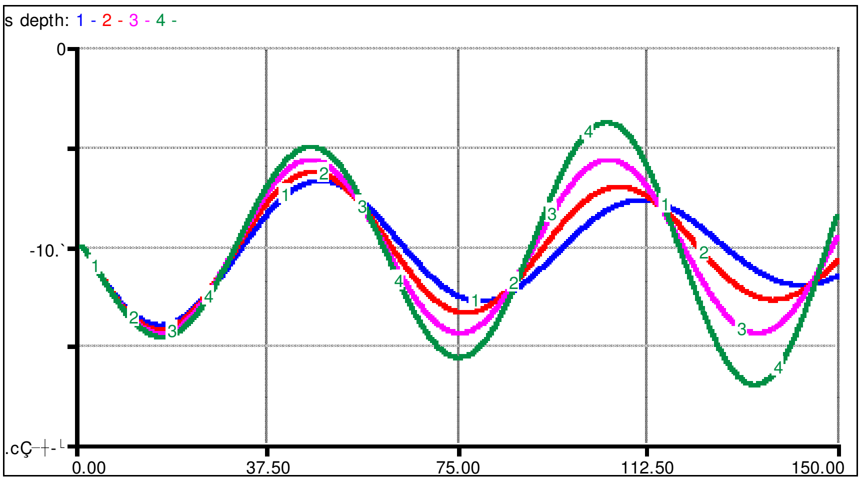



Figure 4.10. Simulations with depth perception equals to 3 sec and velocity perception is varied (1:1, 2:3, 3:5 and 4:7 seconds): information delay in environment

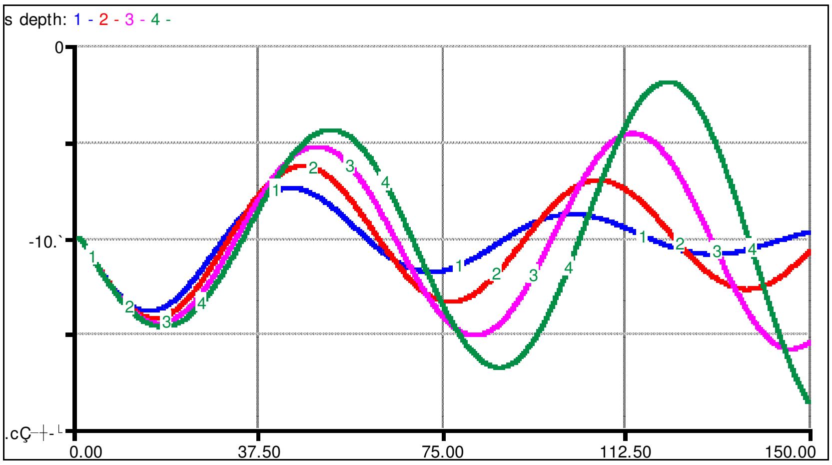



Figure 4.11. Simulations with velocity perception equals to 3 sec and depth perception is varied (1:1, 2:3, 3:5 and 4:7 seconds): information delay in environment

### 4.4.3. Material Delay Exists

Another version of games contains material delay. Although material delay is 0.5 seconds in the game, in this analysis material delay is taken to be 1 second. The corresponding decision making structure may be modeled as in Figure 4.12.

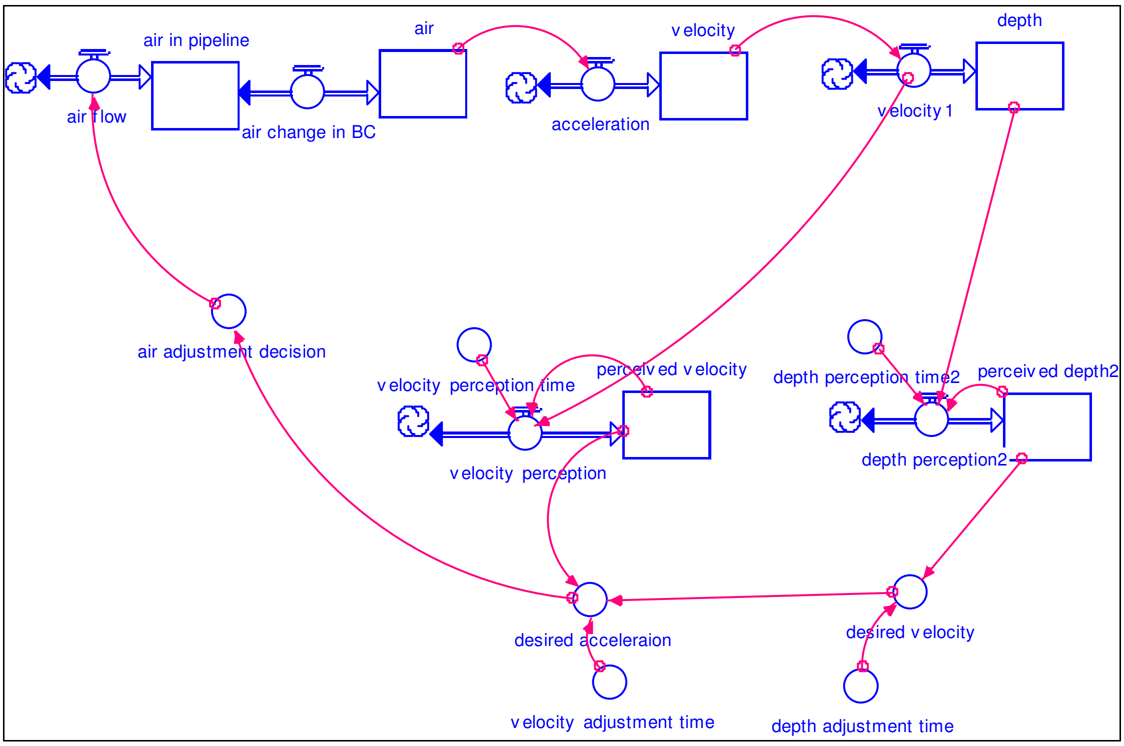



Figure 4.12. Structure of the subjects' decision process: material delay exists

As seen in Figure 4.13, with velocity perception fixed at 3 seconds, increase in depth perception changes the behavior of the system from damping oscillations to growing oscillations. However, when depth perception is fixed at 3 seconds and velocity perception is increased, behavior remains the same, damping oscillations (See Figure 4.14). Thus, it may be said that depth perception is more influential on behavior than velocity perception.

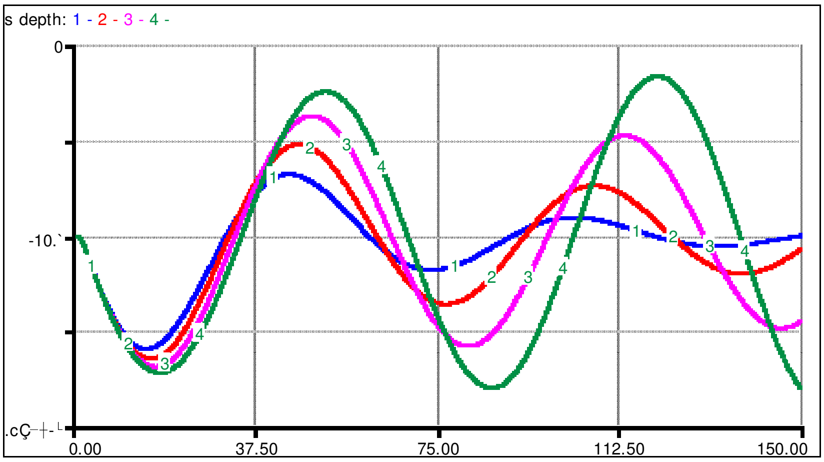



Figure 4.13. Simulations with velocity perception equals to 3 sec and depth perception is varied (1:1, 2:3, 3:5 and 4:7 seconds): material delay in environment

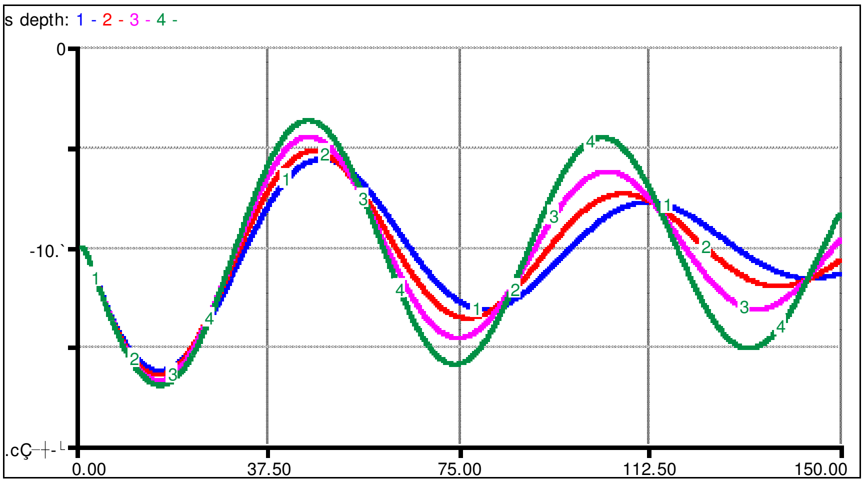



Figure 4.14. Simulations with depth perception equals to 3 sec and velocity perception is varied (1:1, 2:3, 3:5 and 4:7 seconds): material delay in environment

### 4.4.4. Both Material and Information Delay Exist

The last version of the games contains both depth information delay and material delay. Each of them is 1 second long. The structure of the subjects' decision process can be seen in Figure 4.15.

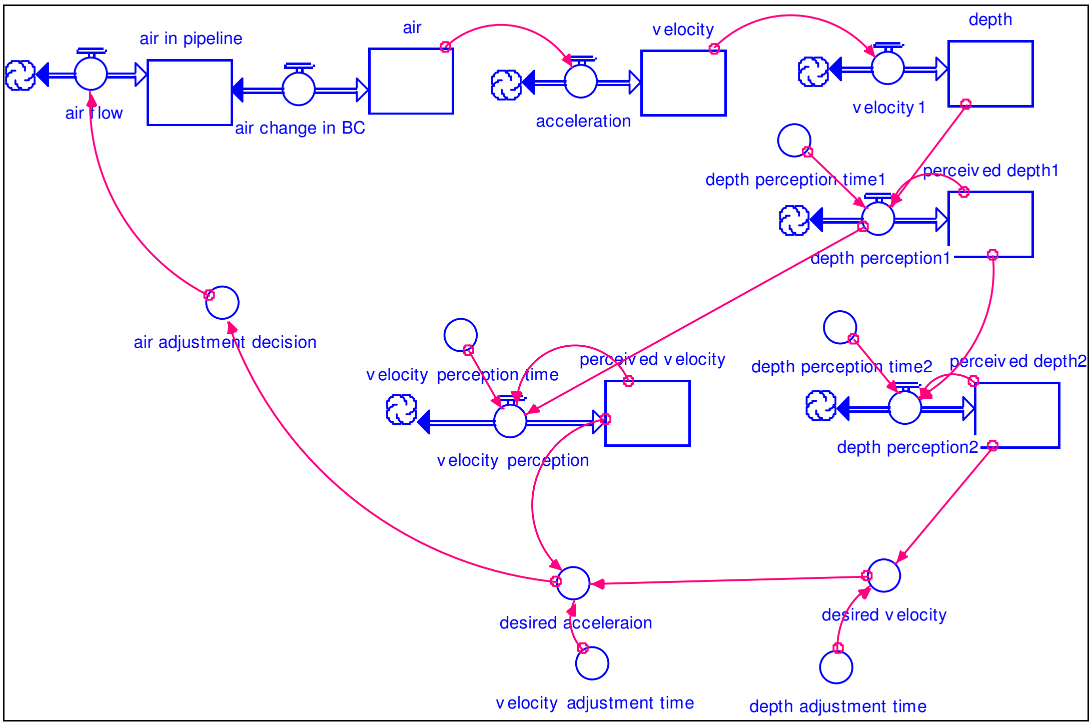



Figure 4.15. Structure of the subjects' decision process: both delays exist

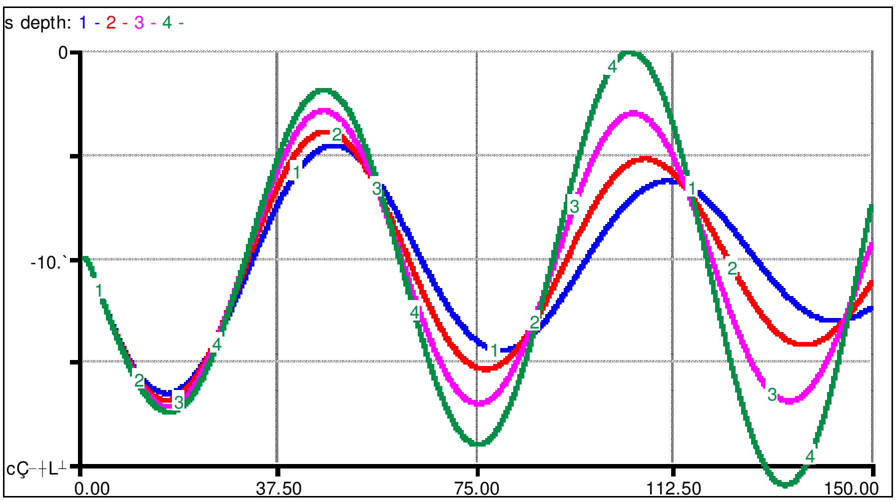



Figure 4.16. Simulations with depth perception equals to 3 sec and velocity perception is varied (1:1, 2:3, 3:5 and 4:7 seconds): both delays in environment

When there are material delay and depth information delay, oscillations have larger amplitudes. Additionally, as subject has velocity and depth perception delays, the amplitudes of these oscillations are further increased. Additionally, the behavior of the model is changed from damping oscillations to growing oscillations as these perception times are large enough.

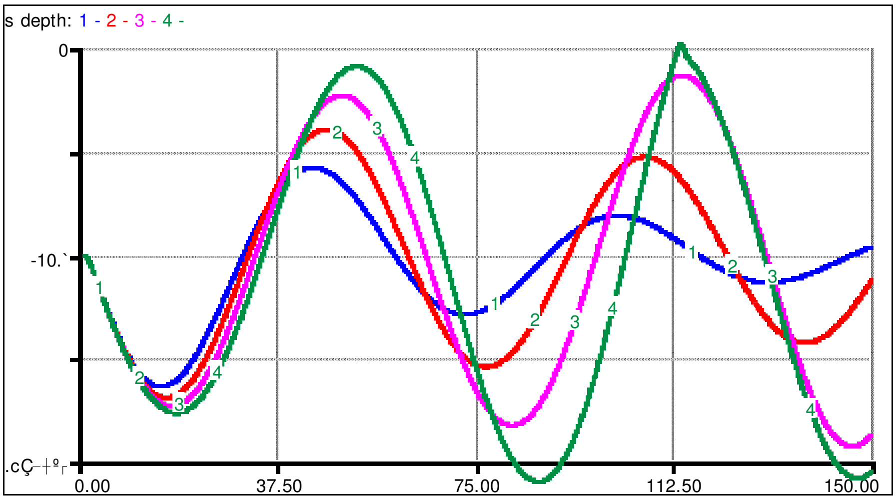



Figure 4.17. Simulations with velocity perception equals to 3 sec and depth perception is varied (1:1, 2:3, 3:5 and 4:7 seconds): both delays in environment

## 4.5. Experimental Design

ScubaSim is a model of a real system in which decision quantities are discrete but made continuously. Since the game is a simplified version of diving system, one hypothesis is that there will be a significant difference between divers and subjects who has not dived previously.

Secondly, subjects have less time to perceive the situation and dynamics of the game if the simulation is fast since decisions are made continuously. Thus, the speed of the game will be an influential variable on performance. The hypothesis with game speed is that when the speed is high, it will be harder to control the system since any delay or erroneous decision will result in more problematic situations in fast games compared to slow games.

Thirdly, decisions are discrete which can be classified as (-1, 0, 1). The decision is multiplied by the constant air flow volume. If the air flow volume is increased as an experimental factor, it is not obvious whether it has positive or negative effects on performance. Thus, the game will be played with high and low air flow volume to account the effects on performance.

Moreover, there are material delay in air flow and information delay in depth perception. The effect of these delays will be also analyzed in the experiments.

The objective of the game is equilibrating at 10 meters. However, the diver may be initially at the surface or at 10 meters depth in equilibrium. In 10 meters initialization games, system is disturbed by deflating ¼ of air in BC at t=5 however there is not any disturbance in games starting at surface.

Two different experimental designs are utilized to analyze the data. In the first one, Latin Square Design, 16 subjects play eight different types of the game. The required number of subjects is not very high but the drawback of Latin Square Design is that it can not analyze any interaction effects. With the results obtained from Latin Square Design, a second experimental design is used for further analysis. In repeated measures experimental design, each version of game is played by a number of subjects and each subject plays the same game six times. With this design, learning effect, effects of scuba diving experience and delays are further analyzed.

### 4.6. Performance Measures

The aim in the game is to stabilize at the desired depth as soon as possible. For evaluating the success of the subject with respect to the given objective, some performance measures are defined. It would be better to have a single performance measure; however, there are different aspects of stability so that a number of performance measures are utilized. For instance, a subject may experience large amplitude oscillations with a longer period whereas another subject may experience small amplitude oscillations with shorter periods. The second one settles in a smaller range than the first one, but the first one does not change his position as much as the first subject does.  Moreover, one subject may be stable at a depth value different than the desired one whereas another subject may have large oscillations with a mean depth value equal to the desired one. To discriminate performances of these subjects, performance measures are created which measure some characteristics of being stable at the desired depth.

Games should be divided into two groups depending on the performance measures used. A game starting at 10 meters depth (with initial disturbance) has different characteristics than games starting at the surface. The most important difference is transient dynamics in surface games. Two typical examples of game results can be seen in Figure 4.18.

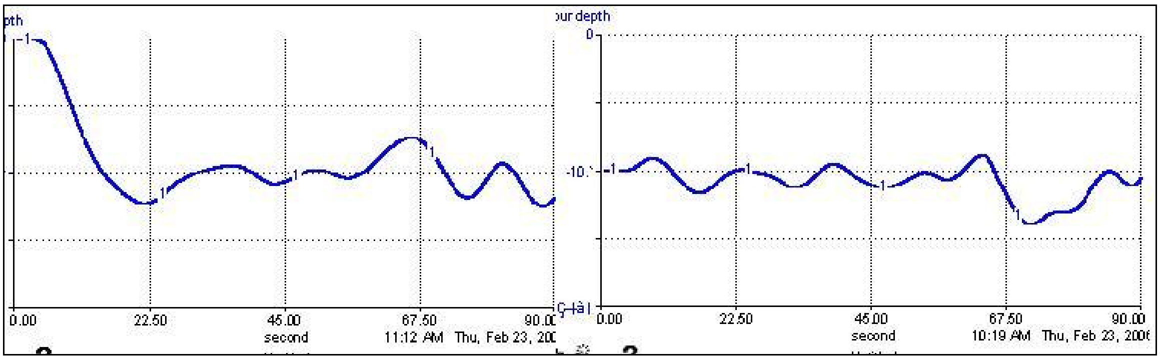



Figure 4.18. Typical examples of game results in games initialized at the surface and at 10 meters depth initially

### 4.6.1. Primary Performance Measures

To evaluate the deviation from desired depth, *deviation area from 10 meters* (*Dev-10-mt*) is calculated. The calculated area is the region between depth trajectory and 10 meters line. If the subject is not stable at desired depth then the value of this performance measure will be high. In surface games, some subjects may wait for a while before they start deflating and this would introduce a bias in the area measure. To avoid this bias in surface games, area calculation starts at time point when subject first decides to deflate air. Total area between depth function and 10 meters line is then divided by the time length of integration, from the time the subject deflates air to t=90 when simulation is ended. Thus, *time average of dev-10-mt* is obtained, independent from the time point the subject first deflates air. The formulation of *dev-10-mt* is

$$\text{Dev-10-mt (t+dt)=Dev-10-mt (t)+abs[depth(t+dt)-10]*dt} \qquad (4.2)$$

*Dev-10-mt* is used as the main, default performance measure in all analysis, unless otherwise stated. Additionally, reward amount is decided depending on *dev-10-mt* scores of subjects.

The second performance measure is basically summation of amplitudes of oscillations. The performance measure is called *total amplitude of fluctuations* (*amp-of-fluct*). *Amp-of-fluct* performance measure is independent of desired depth. It just evaluates how stable the subject is during the game. The formulation of *amp-of-fluct* is as follows:

$$\text{Amp-of-fluct(t+dt)=amp-of-fluct (t)+abs[depth(t+dt)-depth(t)]*dt} \qquad (4.3)$$

For surface games, calculations are started at time point t where subject first crosses 10 meter depth and the summation is then divided by time period during which summation is made.

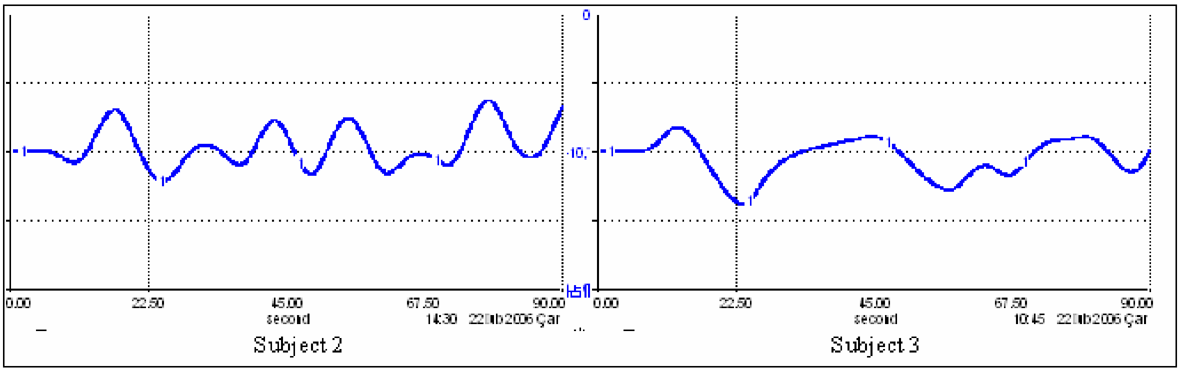



Figure 4.19 Output behaviors obtained by subject 2 and 3 in game type 4

Two typical game results are shown to explain differences between *dev-10-mt* and *amp-of-fluct* performance measures. The output behaviors obtained by subject 2 and 3 in game type 4 (low speed, delay and high flow volume) can be seen in Figure 4.19. They have scores 103 and 102 with respect to *dev-10-mt*; however they have 46 and 26 with respect to *amp-of-fluct*. Thus, *dev-10-mt* performance measure can not differentiate these two games whereas *amp-of-fluct* can.

Another primary performance measure is *maximum deviation from 10 meters (max-dev-10)*. As understood from its name, it basically measures maximum deviation from 10 meters throughout the game. This performance measure is used for both game versions.

The last performance measure for games initialized at 10 meters depth is ±*2 settling time*. With the effect of disturbance applied at t=5, subjects may get far away from desired depth. However, subjects are expected to settle down and be stable in a depth range. With this performance measure, the time point after which subjects stays between 8 meters and 12 meters (10 ±2 meters) is used for measuring stability. This measure is only utilized for games initialized at 10 meters depth with a disturbance away from it.

In the surface games, one interesting characteristic of the behavior is the depth value at which the velocity first equals to zero. It is named as *deviation from 10 meters in first oscillation*. It basically shows how successful subject is in stabilizing at desired depth game objective at first attempt. For some subjects, this depth value may be below 10 meters, which means that they are late to decrease their velocity. For others, this value may be above 10 meters, which means that they are early on decreasing velocity. It may seem earliness-tardiness problem in scheduling.

### 4.6.2. Secondary Performance Measures

Additional performance measures which are classified as secondary performance measure are utilized to evaluate success in stability at the desired depth. *Deviation of mean from 10 meters* (*Dev-mean-10mt)* and *Deviation Area from Mean (Dev-area-mean)* are two secondary measures. The mean depth value and *dev-mean-10mt* are calculated by the following formulation.

$$\text{Mean} = 1/90 * \sum_{t=0}^{90} depth(t) \tag{4.4}$$

$$\text{Dev-mean-10mt} = \text{abs (Mean-10)} \tag{4.5}$$

*Dev-10-mt* was presented above as a primary measure. *Dev-area-mean* is very similar to *dev-10-mt* performance measure. With this measure, area between depth trajectory and mean depth line, instead of 10 meters line, is calculated. The value of *dev-10-mt* may be very high due mean depth value. Subject may be stable in a depth value different than the desired one. For this reason, it is found that *Dev-area-mean* performance measure may be a useful measure of stability.

$$\text{Dev-area-mean}(t+dt)=\text{Dev-area-mean}(t)+\text{abs}[\text{depth}(t+dt)-\text{Mean}]*dt \qquad (4.6)$$

These measures are also used for surface games but with modifications. Since the diver will be at surface initially, summation for mean depth value is started at time *t* where the diver first crosses 10 meters. Also for *Dev-area-mean* measure, summation is not started at t=0 but at the time t when the subject first crosses 10 meters. Then, the summation is divided by the period of time where integration is done since subjects may cross 10 meters level at different time points.

Another secondary performance measure is *maximum amplitude of oscillations (max-amp-osc)*. Maximum of the amplitude of oscillations is a good indicator for the instability degree of the subject. This performance measure is used for both games.

Next performance measure is called *Caisson disease risk index* (*Caisson-RI)*. The divers with a high velocity may have caisson disease as the nitrogen level in their blood changes very rapidly. Also, there may be other problems in ears, sinuses and some other parts of the body where there are cavities. Since there is risk above certain speeds, risk index increases when speed passes some limits. Since the speed limits are not certain and depend on individuals, two limits are chosen to be 0.9 m/sec and 1.8 m/sec for upward and downward motions respectively.

Caisson-RI(t) = Caisson-RI(t - dt) + ((inflow(t)) * dt
Inflow(t)= IF(velocity1<-0.9)
THEN(velocity1*velocity1)
else( if(velocity1>1.8) (4.7)
then (velocity1*velocity1)
else (0))

Lastly, for games starting at surface, the *depth range for last 20 seconds* measure is utilized. This performance measure basically calculates the range in which diver stays for last 20 seconds of the game. It is similar to *±2 settling time* (in which for a given depth, a time period is found) whereas with this measure, for a given time period, a depth range is found.

Table 4.1. Allocation of primary and secondary performance measures to games, depending on initial position

| | Games Starting | |
|---|---|---|
| | At 10 meters depth | At Surface |
| Primary Performance Measures | Deviation Area from 10 meters | Time Average of Deviation Area from 10 meters |
| | Total Amplitude of Fluctuations | Time Average of Total Amplitude of Fluctuations |
| | Maximum Deviation from 10 meters | Maximum Deviation from 10 meters |
| | ±2 Settling Time | Deviation from 10 meter in first oscillation |
| Secondary Performance Measures | Deviation of Mean From 10 meters | Deviation of Mean From 10 meters |
| | Deviation Area from Mean | Time Average of Deviation Area from Mean |
| | Maximum Amplitude of Oscillations | Maximum Amplitude of Oscillations |
| | Caisson Disease Risk Index | Depth Range for Last 20 seconds |

# 5. RESULTS OF LATIN SQUARE EXPERIMENTS

The experiments used in data analysis with Latin square design can be divided into two sub-groups. Eight subjects in first group play the games in which initial position is 10 meters and eight subjects in the second group play the games in which the initial position is surface. Game numbers and properties of games can be seen in Table 5.1.

Table 5.1. Properties of games used in Latin square experimental analysis

| Game type | Game speed | Delay | Flow volume |
|---|---|---|---|
| 1 | low | not present | low |
| 2 | low | not present | high |
| 3 | low | present | low |
| 4 | low | present | high |
| 5 | high | not present | low |
| 6 | high | not present | high |
| 7 | high | present | low |
| 8 | high | present | high |

The eight subjects in each group will play all these eight games but with a different sequence. The scores obtained in each of these eight games also depend on differences between subjects and practice gained. With Latin square design, these two nuisance factors will be analyzed independently and will not affect the overall results of game speed, delay and air flow volume.

Diehl and Sterman analyzed 15 different games with 15x15 Latin Square Design. Each of 15 subjects played 15 different games with different sequence. 15 games played in four sessions because total length of experiments is 6 hours (Diehl and Sterman, 1995). In Scubasim experiments, each game takes 2:23 or 4:50 minutes depending on the game speed. Since it does not take to much time, all games are played in one session.

As seen in Table 5.2, each subject plays all eight different types of the game but with a different sequence. The random table is obtained with the use of program called random2.exe which is developed by Byers (Byers, 1993). Additionally, all types of the game are played by eight subjects but in a different position. With this property of the design, practice effect, effect of air flow volume, delays, game speed, prior scuba diving experience and system dynamics knowledge will be tested for statistical significance.

Table 5.2 Order of the games played by each subject (Numbers are game type numbers in Table 5.1)

| | Subject1 | Subject2 | Subject3 (Diver) | Subject4 (Diver) | Subject5 (SD) | Subject6 (SD) | Subject7 (Diver-SD) | Subject8 (Diver-SD) |
|---|---|---|---|---|---|---|---|---|
| Trial 1 | 7 | 8 | 1 | 2 | 5 | 4 | 3 | 6 |
| Trial 2 | 3 | 4 | 5 | 6 | 1 | 8 | 7 | 2 |
| Trial 3 | 5 | 6 | 7 | 8 | 3 | 2 | 1 | 4 |
| Trial 4 | 2 | 3 | 4 | 5 | 8 | 7 | 6 | 1 |
| Trial 5 | 1 | 2 | 3 | 4 | 7 | 6 | 5 | 8 |
| Trial 6 | 6 | 7 | 8 | 1 | 4 | 3 | 2 | 5 |
| Trial 7 | 8 | 1 | 2 | 3 | 6 | 5 | 4 | 7 |
| Trial 8 | 4 | 5 | 6 | 7 | 2 | 1 | 8 | 3 |

Latin Square experiments will be presented in two subgroups; games initialized at 10 meters depth and at surface. Eight subjects (subject 1 to subject 8) played games initialized at 10 meters whereas eight subjects (from subject 9 to subject 16) played the games initialized at surface. However, for games initialized at surface, two subjects who had system dynamics knowledge and scuba diving experience could not be found, so subject 15 is chosen to be a diver and subject 16 is chosen to have system dynamics knowledge.

With Latin square experiments, the effects of delay, game speed, and air flow volume are analyzed. Besides these effects, it is also investigated whether there are differences between subjects. Additionally, it is also examined whether there is significant learning throughout the experiments.

Excel software is utilized for analysis of variance. Here, the formulations used for calculating sum of square values will be presented. Our statistical model is as in Equation (5.1), where $x_{ijk}$ is the score obtained in *i*th trial by subject *k* which is game type *j* and $\mu$ is overall mean, $\alpha_i$ is the effect of trial *i,* $\tau_j$ is the effect of game type *j* and $\beta_k$ is the effect of subject *k* (Montgomery, 1997). Only two of three subscripts are required to uniquely represent an observation. For instance, when *i*=1 and *j*=1, *k* automatically will be 3, since game type 1 is played in first trial only by subject 3. Thus, there will be 8x8 experiments instead of 8x8x8 experiments in Latin Square design. Although low number of subjects is an advantage, interaction effects can not be investigated with this design.

$$x_{ijk}=\mu+\alpha_i+\tau_j+\beta_k+\varepsilon_{ijk} \qquad i,j,k=1,2...,8 \tag{5.1}$$

Our hypotheses are:

$H_0(1)$: $\alpha_1=\alpha_2=\ldots=\alpha_8$

$H_1(1)$: At least one $\alpha_i$ is different from others

$H_0(2)$: $\tau_1=\tau_2=\ldots=\tau_8$

$H_1(2)$: At least one $\tau_i$ is different from others

$H_0(3)$: $\beta_1=\beta_2=\ldots=\beta_8$

$H_1(3)$: At least one $\beta_i$ is different from others

To test these hypotheses, $SS_{trial}$, $SS_{game\ type}$, $SS_{subject}$, $SS_{error}$ and $SS_{total}$ are computed for each performance measure. The formulations for sum of square values can be seen in Equation (5.2).

$$SS_{trial}=\frac{1}{8}\sum_i\left(\sum_j\sum_k x_{ijk}\right)^2-\frac{1}{64}\left(\sum_i\sum_j\sum_k x_{ijk}\right)^2$$

$$SS_{game\ type}=\frac{1}{8}\sum_j\left(\sum_i\sum_k x_{ijk}\right)^2-\frac{1}{64}\left(\sum_i\sum_j\sum_k x_{ijk}\right)^2$$

$$SS_{subject}=\frac{1}{8}\sum_k\left(\sum_i\sum_j x_{ijk}\right)^2-\frac{1}{64}\left(\sum_i\sum_j\sum_k x_{ijk}\right)^2 \tag{5.2}$$

$$SS_{total}=\sum_i\sum_j\sum_k x_{ijk}^2-\frac{1}{64}\left(\sum_i\sum_j\sum_k x_{ijk}\right)^2$$

$$SS_{error}=SS_{total} - SS_{trial} - SS_{game\ type} - SS_{subject}$$

Then, $SS_{game\ type}$ is further divided into sub sum of square values to evaluate the effect of game speed, delay, air flow volume and their 2-way and 3-way interactions. For each effect, game scores obtained in low and high levels are found. For instance, formulation of $SS_{game\ speed}$ is as follows:

$$SS_{game\ speed}=\frac{1}{64}\left(\sum_{\substack{high\\game\\speed}} x_{ijk}-\sum_{\substack{low\\game\\speed}} x_{ijk}\right)^2 \tag{5.3}$$

Sum of square values are divided by degrees of freedom values to find mean square values (See Table 5.3). For each effect, mean square value is divided by mean square error and F value is obtained. Depending of the F and degrees of freedom values of the effect, P value is found.

Table 5.3. Degrees of freedom values of the effects

| | Source of Variation | Degrees of Freedom |
|---|---|---|
| Game Type-Total | | 7 |
| Game Type | Game Speed | 1 |
| | Delay | 1 |
| | Flow Volume | 1 |
| | Game Speed x Delay | 1 |
| | Game Speed x Flow Volume | 1 |
| | Delay x Flow Volume | 1 |
| | Game Speed x Delay x Flow Volume | 1 |
| Subject | | 7 |
| Practice | | 7 |
| Error | | 42 |
| Total | | 63 |

For model adequacy, normal probability plot of residuals, plot of residuals by game type, by trial and by subject and by fitted values, $\hat{x}_{ijk}$ are investigated. Residuals should be distributed normally with $(0, \sigma^2)$. Additionally, variances should be equal among subjects, trials and game types. If these assumptions do not hold, transformation of variables will be applied and analysis will be done with transformed data.

## 5.1. Games Initialized at 10 Meters Depth

There are eight different performance measures, four of which are primary and the rest are secondary. Results depending on primary measures will be presented in this section whereas results of secondary measures can be seen in Appendix D. The primary performance measures are *dev-10-mt*, a*mp-of-fluct*, *max-dev-10* and *±2 settling time* whereas secondary performance measures are *dev-mean-10mt, dev-area-mean, max-amp-osc* and c*aisson-RI.*

Figure 5.1 shows four typical game output results obtained under different game settings played by different subjects. The upper left game does not contain any delay and is played under low speed. The subject is successful to maintain stability around the desired depth. The upper right game is played in delay condition. When compared with previous one, it is seen that amplitude of oscillations increases significantly. The game in the lower left part of Figure 5.1 is played without delay but the game speed is high. As compared with the low speed game, it is seen that frequent oscillations are seen. Lastly, game output in the lower right belongs to a delay game and is played under high speed. A large oscillation is created where the stability is very poor. It has to be mentioned that these games are played by different subjects and in different orders. Thus, output behaviors also depend on differences between subjects and practice through trials. Complete game results obtained in games initialized at 10 meters by subjects 1-8 can be seen in Appendix F.

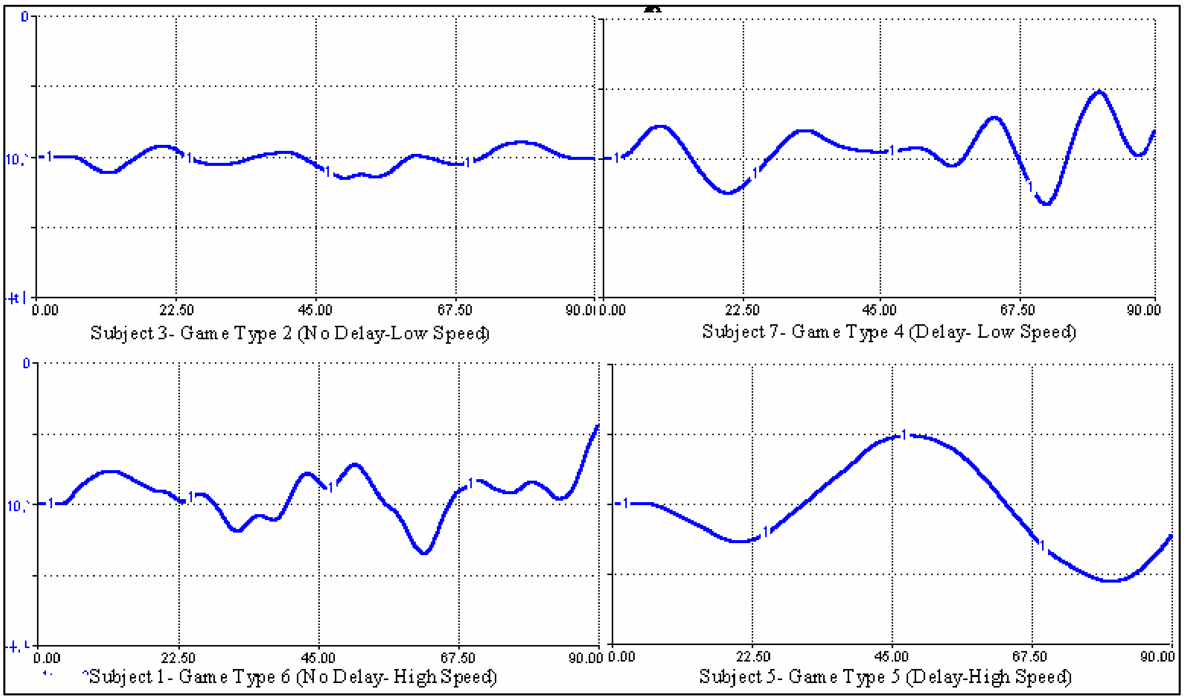



Figure 5.1. Typical results obtained in games initialized at 10 meters

Before going into detailed statistical analysis, it is useful to show scores obtained by subjects in different game settings and different trials. *Dev-10-mt* performance measure is used for numerical illustrations. Scores obtained with this measure can be seen in Table 5.4. Similar tables for other performance measures can be seen in Appendix D.

Minimum score obtained is 30 whereas maximum score is 593. When the total scores of subjects are analyzed, it is seen that subjects having scuba diving experience

(Scuba) performed better than other subjects. Subjects having system dynamics knowledge (SD) are not more successful than subjects not having. Total score of subjects in first trial is 1758, whereas it is 835 in the last. As trial totals are investigated, it is seen that there are significant differences between trials. However, a continuous improvement can not be observed. When total scores obtained at each game type are investigated, it is seen that they are varied between 804 and 1955 where games can be divided into two groups depending on total scores. The group with good scores includes the games without delay, whereas the group with poor scores contains the games with delay (if we neglect 4$^{th}$ game in which delay is present but total score is medium).

Table 5.4 Scores of games initialized at 10 meters depth: *dev-10-mt* measure

| | Subject1 | Subject2 | Subject3 | Subject4 | Subject5 | Subject6 | Subject7 | Subject8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | SD + Scuba1 | SD + Scuba2 | Trial i total | Game j total |
| Trial 1 | 482 | 369 | 61 | 82 | 313 | 99 | 256 | 97 | 1758 | 804 |
| Trial 2 | 209 | 103 | 62 | 73 | 270 | 275 | 200 | 39 | 1230 | 886 |
| Trial 3 | 209 | 200 | 120 | 188 | 345 | 409 | 76 | 71 | 1619 | 1955 |
| Trial 4 | 50 | 227 | 102 | 67 | 111 | 324 | 103 | 47 | 1031 | 1005 |
| Trial 5 | 94 | 131 | 178 | 104 | 246 | 173 | 216 | 211 | 1353 | 1080 |
| Trial 6 | 120 | 186 | 175 | 30 | 308 | 593 | 54 | 62 | 1528 | 877 |
| Trial 7 | 228 | 74 | 47 | 82 | 59 | 49 | 129 | 87 | 755 | 1748 |
| Trial 8 | 88 | 102 | 52 | 104 | 74 | 153 | 196 | 66 | 835 | 1753 |
| Subject k total | 1481 | 1392 | 796 | 731 | 1726 | 2074 | 1229 | 679 | 10109 | 10109 |

Table 5.5. Contrast values of effects in games initialized at 10 meters

| | Deviation Area from 10 meters | | Total Amplitude of Fluctuations | | Maximum Deviation from 10 meters | | ±2 settling time | |
|---|---|---|---|---|---|---|---|---|
| | low | high | low | high | low | high | low | high |
| Game Speed | 4650 | 5459 | 846 | 1106 | 149 | 167 | 1867 | 2260 |
| Delay | 3647 | 6462 | 772 | 1180 | 120 | 196 | 1479 | 2648 |
| Flow Volume | 5588 | 4521 | 858 | 1094 | 162 | 154 | 2053 | 2074 |
| Game Speed x Delay | 4918 | 5191 | 978 | 975 | 154 | 162 | 2182 | 1945 |
| Game Speed x Flow Volume | 4720 | 5389 | 872 | 1080 | 144 | 172 | 1872 | 2255 |
| Delay x Flow Volume | 5467 | 4642 | 930 | 1023 | 166 | 150 | 2094 | 2033 |
| Game Speed x Delay x Flow Volume | 4435 | 5674 | 895 | 1058 | 139 | 177 | 2086 | 2041 |

When distribution of scores are analyzed depending on game attributes, it is seen that total scores obtained in high speed games differ from low speed games with respect to *amp-of-fluct* and *±2 settling time* performance measures. However differences are not significant with other primary performance measures (*dev-10-mt* and *max-dev-10*). This is one of the interesting observations since game speed is expected to have one of the most significant effects on game performance (Gonzalez, 2004).

As expected, delay has a significant effect on game performance (Diehl and Sterman, 1995). When delay is present, game scores are observed to be very poor. Existence of delays deteriorates performances of subjects. Additionally, there is a slight difference on scores depending on the level of flow volume. Moreover, there are two-way and three-way interaction effects which seem to be significant. Total scores obtained by subjects within different game settings can be seen in Table 5.5. Similar results for secondary performance measures are presented in Appendix D.

Table 5.6. ANOVA table for primary performance measures for games initialized at 10 meters depth (after log transformation of *dev-10-mt* scores)

| | | Deviation Area from 10 meters | | Total Amplitude of Fluctuations | | Maximum Deviation from 10 meters | | ±2 settling time | |
|---|---|---|---|---|---|---|---|---|---|
| | Source of Variation | SS | P-value | SS | P-value | SS | P-value | SS | P-value |
| GameType-Total | | 8.92 | 0 | 5754 | 0,00 | 135 | 0,00 | 27008 | 0,00 |
| Game Type | Game Speed | 1.12 | 0.02 | 1055 | 0,00 | 5 | 0,26 | 2407 | 0,04 |
| | Delay | 6.48 | 0 | 2603 | 0,00 | 90 | 0,00 | 21324 | 0,00 |
| | Flow Volume | 0.31 | 0.21 | 869 | 0,00 | 1 | 0,58 | 6 | 0,91 |
| | Game Speed x Delay | 0 | 0.91 | 0 | 0,96 | 1 | 0,64 | 883 | 0,21 |
| | Game Speed x Flow Volume | 0.35 | 0.19 | 674 | 0,00 | 12 | 0,08 | 2298 | 0,04 |
| | Delay x Flow Volume | 0.13 | 0.43 | 136 | 0,18 | 4 | 0,30 | 58 | 0,74 |
| | Game Speed x Delay x Flow Volume | 0.53 | 0.11 | 417 | 0,02 | 22 | 0,02 | 32 | 0,81 |
| Subject | | 8.12 | 0 | 3070 | 0,00 | 137 | 0,00 | 10271 | 0,02 |
| Practice | | 4.26 | 0.01 | 1778 | 0,01 | 92 | 0,00 | 8104 | 0,06 |
| Error | | 8.29 | | 3133 | | 155 | | 22449 | |
| Total | | 29.6 | | 13735 | | 519 | | 67832 | |

Although numerical comparisons give insight about significance of effects, statistical analysis should be carried out for more accurate comparisons. For *dev-10-mt, dev-mean-10mt, Dev-area-mean and maximum amplitude of oscillations* performance measures, it is seen that there is an increasing trend in magnitude of residuals with respect to fitted values, $\hat{x}_{ijk}$. Thus, natural logarithmic transformation is applied and analysis is redone with transformed data. With transformed data, it is observed that there is not any severe violation of normality assumption and equality of variances assumption between subjects, trials and game types. In the following statistical analysis, transformed data is used when violation of normality assumption is observed in the original data. ANOVA table for primary performance measures can be seen in Table 5.6 (See Appendix D for secondary performance measures).

As the ratio between $SS_{Error}$ and $SS_{Total}$ is subtracted from one, we obtain the percentage variation that can be explained by the model variables. It is seen in Table 5.6 and Appendix D that percentage of variation that can be explained by model variables is between 66% and %77 for primary performance measures, 44% to 72% for secondary performance measures. The values are found satisfactory for such experimentations.

As ANOVA table is investigated, it is seen that game type, subject effect and practice effect are all found to be significant for all four primary performance measures. Thus, we can safely conclude that there are significant differences between subjects, game types and trials. Since differences between subjects are found to be significant, blocking will be used in the next experimental setting, repeated measures experiments. Additionally, it is found that there are significant differences between trials, but we can not conclude that subjects' performances improved throughout experiments. Pair-wise comparisons should be conducted between each consecutive trial to make safe and sound conclusions about learning or improvement. Thus, further experiments should be conducted to find whether there is significant improvement throughout trials.

It is found that delay effect is significant for all four primary performance measures. Game speed is also found significant for all performance measures but *max-dev-10*. Additionally, flow volume is found significant for *amp-of-fluct* measure. More interestingly, game speed-flow volume interaction effect and game speed- flow volume-delay 3-way interaction effect are also found significant.

Figure 5.2 shows (game speed) x (flow volume) interaction effect for *amp-of-fluct* performance measure. When flow volume is low, there is not a significant change in score with respect to low and high speed games. As flow volume is increased to high level, score is significantly affected by the game speed. Although, in both high and low flow volume, increase in game speed deteriorates performance, the deterioration is much higher in high flow volume games.

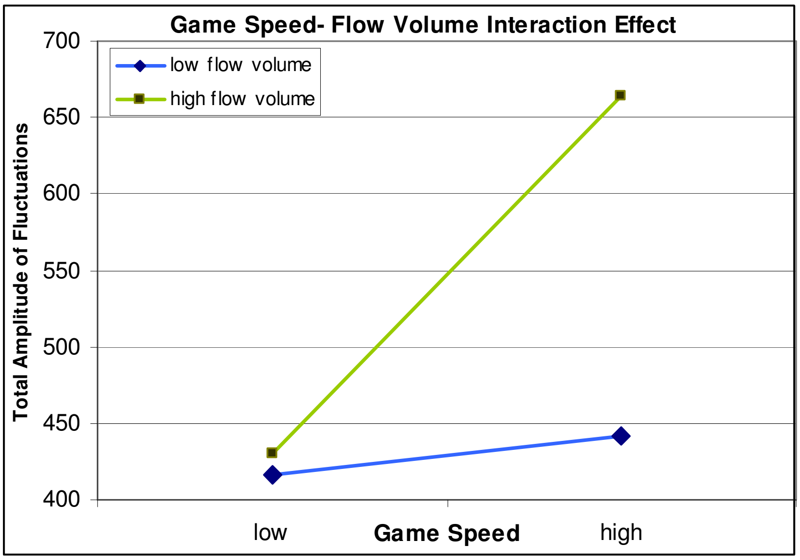



Figure 5.2. (Game speed) x (Flow volume) interaction effect for games starting at 10 mt

As mentioned previously, scores obtained by different subjects differ significantly. As natural logarithms of total scores obtained with respect to *dev-10-mt* performance measure are utilized in a $2^2$ factorial design with two replicates, Table 5.7 is obtained. Scuba diving experience is found to be significant whereas system dynamics knowledge is found to be insignificant. Estimated mean score is 7.07 whereas scuba diving experience results in a score improvement by 0.34. Thus, estimated total score for non scuba divers is 1.4 times of overall mean whereas for scuba divers it is 0.7 times of overall mean.

Table 5.7. ANOVA table for differences between subjects: *dev-10-mt* measure (with log transformed data)

| Source | SS | DF | Mean Square | F Value | Prob > F |
|---|---|---|---|---|---|
| Model | 1.03 | 3 | 0.34 | 6.96 | 0.05 |
| Scuba Diving Experience | 0.93 | 1 | 0.93 | 18.69 | 0.01 |
| System Dynamics Knowledge | 0.1 | 1 | 0.1 | 2.1 | 0.22 |
| Scuba x System Dyn. | 0 | 1 | 0 | 0.09 | 0.78 |
| Residual | 0.2 | 4 | 0.05 | | |
| Cor Total | 1.23 | 7 | | | |

Addition to differences between subjects, similar analyses are done for other performance measures. Results can be classified into two groups. Scuba diving experience and system dynamics knowledge are found to be insignificant with respect to *amp-of-fluct,* and *Caisson-RI*. However, for *dev-mean-10mt*, *dev-area-mean*, *max-dev-10*, *± 2 settling time* and *max-amp-osc* performance measures, scuba diving experience is found to be significantly effective on performance. In this analysis, it is found that scuba diving experience improved performance whereas system dynamics knowledge did not affect performance. Since sample size is low and other individual differences might be effective on performance, effect of scuba diving experience should be analyzed more extensively for a sound conclusion.

## 5.2. Games Initialized at Surface

While games initialized at 10 meters depth primarily focus on behavior of subjects in the existence of a disturbance, games initialized at surface focus on behavior when a target depth value is given. Although decision processes are expected to be similar in these two conditions, the output behaviors may differ. For this reason, similar (but not exactly the same) performance measures are utilized for games starting at surface as explained in the Interactive Simulation Game (ScubaSim) chapter.

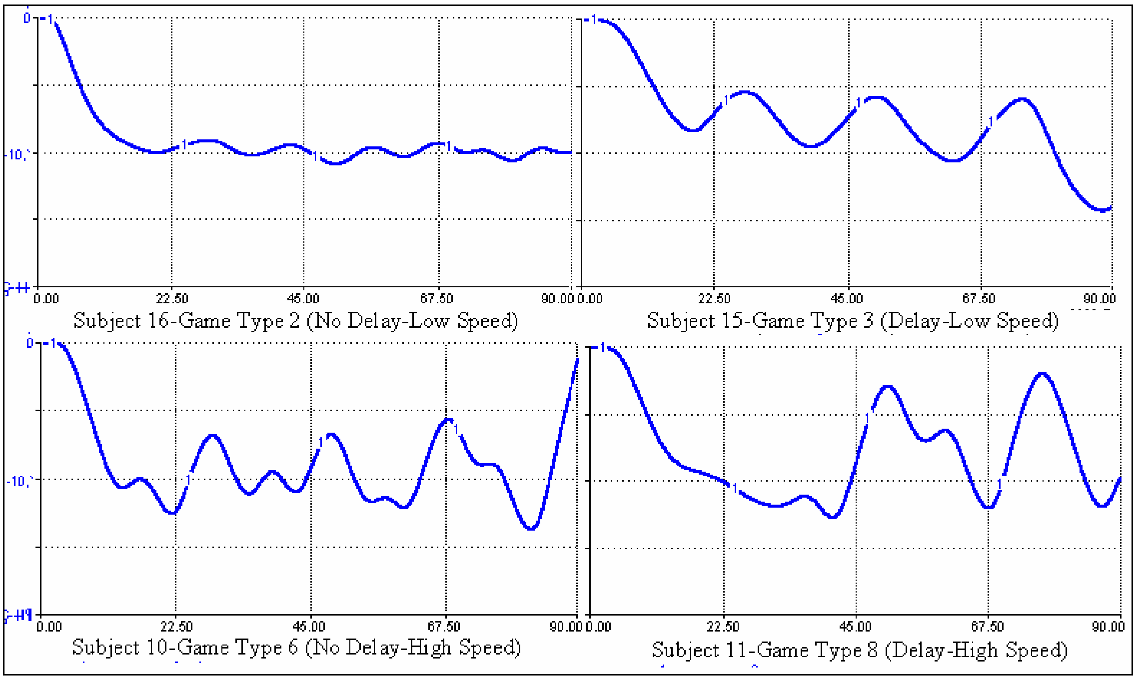



Figure 5.3. Typical results obtained in games initialized at surface

Some output results observed in games initialized at surface can be seen in Figure 5.3. Although differences between subjects, experience gained with practice, air flow volume and its interaction effects with game speed and delays are expected to be significant, the four game results are taken at high and low levels of game speed and delay. Note that differences between results are also dependent on other factors. However, it is significant that existence of delays and high game speed increase the complexity of control and subjects perform worse in these game settings. All eight game results obtained by each of eight subjects playing in games initialized at surface can be seen in Appendix F.

Primary performance measures used in games initialized at surface are *time average of dev-10-mt, time average of amp-of-fluct, max-dev-10* and *deviation from 10 meters in first oscillation*. While analysis of primary measures will be presented in this section, results and ANOVA tables for secondary performance measures can be seen in Appendix D. These secondary performance measures are *dev-mean-10mt, time average of dev-area-mean, max-amp-osc* and *depth range for last 20 seconds*. Before going into detailed statistical analysis, it is useful to present *time average of dev-10-mt* performance measure for all 64 games played.

Table 5.8. Scores of games initialized at surface: *time average of dev-10-mt* measure

| | Subject 9 | Subject 10 | Subject 11 | Subject 12 | Subject 13 | Subject 14 | Subject 15 | Subject 16 | Trial i total | Game j total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | Scuba3 | SD3 | | |
| Trial 1 | 4,38 | 2,19 | 1,93 | 2,78 | 3,05 | 3,83 | 3,17 | 1,73 | 23,06 | 16,55 |
| Trial 2 | 2,98 | 2,66 | 1,82 | 1,37 | 2,67 | 3,25 | 4,40 | 1,04 | 20,20 | 14,76 |
| Trial 3 | 2,12 | 2,24 | 3,06 | 2,99 | 2,43 | 2,66 | 3,43 | 2,05 | 20,97 | 24,47 |
| Trial 4 | 1,46 | 3,05 | 1,94 | 2,07 | 4,02 | 4,74 | 2,22 | 1,49 | 20,99 | 21,02 |
| Trial 5 | 1,35 | 1,57 | 3,53 | 2,32 | 2,57 | 2,88 | 2,64 | 2,24 | 19,09 | 18,59 |
| Trial 6 | 1,69 | 4,25 | 3,17 | 2,37 | 2,78 | 2,65 | 2,06 | 2,09 | 21,07 | 15,78 |
| Trial 7 | 1,65 | 1,88 | 1,34 | 4,03 | 1,93 | 1,86 | 3,44 | 3,41 | 19,54 | 29,97 |
| Trial 8 | 2,00 | 2,94 | 1,71 | 3,16 | 1,86 | 1,43 | 2,43 | 2,63 | 18,17 | 21,94 |
| Subject k total | 17,63 | 20,80 | 18,50 | 21,08 | 21,31 | 23,30 | 23,79 | 16,68 | 163,09 | 163,09 |

As we analyze the scores, it is seen that minimum score is 1.04 whereas maximum score obtained is 4.74. On average, subject 14 in his third trial was 4.74 meters away from desired depth value. On the other hand, subject 16 was only 1.04 meters away from desired depth on average. It has to be mentioned that in the games initialized at surface, there is a large area between depth trajectory and desired depth value 10 meters, in the beginning of the game.

The total scores for each trial vary between 18.17 and 23.06, but there is not any increasing or decreasing trend throughout trials. Thus, a significant practice effect is not observed. Although, we observe a significant difference between scuba divers and non scuba divers in games initialized at 10 meters, at surface games such a significant difference can not be detected. Thus, further experimentation should be done to evaluate practice effect and significance of previous diving experience on performance to make safe and sound conclusion.

When differences depending on game types are analyzed, it is observed that the 1st, 2nd, 5th and 6th game totals are below 19, whereas in the remaining game types, total score is at least 21. The first class of games contains the ones without delays, whereas remaining games include delays in their structures.

Table 5.9. Contrast values of effects in games initialized at surface

| | Time Average of Deviation Area from 10 meters | | Time Average of Total Amplitude of Fluctuations | | Maximum Deviation from 10 meters | | Deviation from 10 meters in first oscillation | |
|---|---|---|---|---|---|---|---|---|
| | low | high | low | high | low | high | low | high |
| Game Speed | 76,81 | 86,28 | 11,47 | 14,18 | 136,49 | 182,34 | 86,81 | 82,59 |
| Delay | 65,69 | 97,40 | 10,08 | 15,56 | 127,23 | 191,59 | 79,27 | 90,13 |
| Flow Volume | 89,59 | 73,50 | 11,82 | 13,82 | 156,29 | 162,54 | 84,51 | 84,89 |
| Game Speed x Delay | 79,86 | 83,23 | 13,13 | 12,51 | 152,68 | 166,14 | 75,77 | 93,63 |
| Game Speed x Flow Volume | 84,35 | 78,74 | 12,79 | 12,85 | 169,63 | 149,19 | 79,86 | 89,54 |
| Delay x Flow Volume | 84,98 | 78,11 | 12,78 | 12,86 | 177,05 | 141,77 | 93,65 | 75,76 |
| Game Speed x Delay x Flow Volume | 83,32 | 79,77 | 13,28 | 12,36 | 172,55 | 146,27 | 72,00 | 97,40 |

When total scores obtained at low and high levels of game attributes are analyzed, the most significant difference is seen in the existence of delays (See Appendix D for secondary measures). Existence of delays deteriorates performance. Game speed is also observed as a significant effect for different performance measures. Although it is not as significant as delay, speed of game also deteriorates performance. For the first three performance measures, it is seen that fast games result in higher scores meaning worse performance.

Before discussing analysis of variance results, model assumptions are checked. It is found that for most of the performance measures, there is not any significant violation of normality assumption and equality of variances between subjects, trials and game types assumption. However, for *dev-mean-10mt, time average of Dev-area-mean* and *depth range for last 20 seconds* secondary measures, departure from normality and magnitude increase in residuals with respect to fitted values are observe. After natural logarithmic transformation, it is observed that assumptions hold. But note that, all tables below dealing with primary measures refer to non-transformed data.

Starting with practice effect, we can not say that there are differences between trials. Since subjects played 8 different games, learning throughout trials might be insignificant. In other words, experience or knowledge might not be transferred between consecutive trials; with delays to without delay, high speed to low speed etc. Continuing with subject effect, it is found to be significant for three primary performance measures. However, differences are mainly in individual level.

Table 5.10. ANOVA table for primary performance measures for games initialized at surface

| | | Time Average of Deviation Area from 10 meters | | Time Average of Total Amplitude of Fluctuation | | Maximum Deviation from 10 meters | | Deviation from 10 meter in first oscillation | |
|---|---|---|---|---|---|---|---|---|---|
| | Source of Variation | SS | P Value | SS | P Value | SS | P Value | SS | P Value |
| Game Type- Total | | 22,77 | 0,00 | 0,67 | 0,00 | 137,78 | 0,00 | 23,66 | 0,69 |
| Game Type | Game Speed | 1,40 | 0,06 | 0,11 | 0,00 | 32,85 | 0,01 | 0,28 | 0,82 |
| | Delay | 15,72 | 0,00 | 0,47 | 0,00 | 64,72 | 0,00 | 1,84 | 0,55 |
| | Flow Volume | 4,04 | 0,00 | 0,06 | 0,03 | 0,61 | 0,72 | 0,00 | 0,98 |
| | Game Speed x Delay | 0,18 | 0,49 | 0,01 | 0,48 | 2,83 | 0,44 | 4,99 | 0,32 |
| | Game Speed x Flow Volume | 0,49 | 0,25 | 0,00 | 0,94 | 6,52 | 0,25 | 1,46 | 0,59 |
| | Delay x Flow Volume | 0,74 | 0,16 | 0,00 | 0,92 | 19,45 | 0,05 | 5,00 | 0,32 |
| | Game Speed x Delay x Flow Volume | 0,20 | 0,47 | 0,01 | 0,29 | 10,79 | 0,14 | 10,08 | 0,16 |
| Subject | | 5,81 | 0,05 | 1,19 | 0,00 | 76,50 | 0,04 | 52,95 | 0,19 |
| Practice | | 1,96 | 0,62 | 0,14 | 0,13 | 42,48 | 0,28 | 17,00 | 0,84 |
| Error | | 15,46 | | 0,50 | | 198,30 | | 211,14 | |
| Total | | 46,00 | | 2,49 | | 455,05 | | 304,75 | |

As total scores obtained with respect to *time average of dev-10-mt* by subjects are used in single factor three level experimental analysis (scuba diving experience, system dynamics knowledge, none), Table 5.11 is found. The differences between groups are not significant. Thus, there is not a significant difference between groups. It can not be concluded that scuba divers performed better than subjects who have not scuba diving experience. The same conclusion is also valid for system dynamics knowledge. Thus, additional experiments will be informative about differences between subjects and learning or improvement throughout trials.

Table 5.11. ANOVA table for differences between groups: time average of dev-10-mt

| Source of Variation | Sum of Squares | DoF | Mean Square | F-value | P-Value |
|---|---|---|---|---|---|
| Subject Groups | 3.71 | 2 | 1.85 | 0.23 | 0.8 |
| Error | 39.64 | 5 | 7.93 | | |
| Total | 43.35 | 7 | | | |

For all performance measures except *deviation from 10 meters in first oscillation*, effect of delay is found to be significant. As previously mentioned, the effect of individual delays, material and information, will be further analyzed. Game speed is also significant on performance. Subjects 9, 10, 11, 12 and 14 explicitly stated that difficulties in obtaining successful results were not due to game speed. However, other subjects stated that game speed was a reason for their worse performances. Flow volume is also effective on performance for some measures but not for all. Contrary to games initialized at 10 meters, in surface games we can not find any significant interaction effect.

When we analyze the percentage of variation that is explained, it is found to be between 60% and %80 for primary performance measures except *deviation from 10 meters in first oscillation* for which this value decreases to 30% (See Table 5.10). For secondary performance measures percentage contribution varies between 66% and 75% except *dev-mean-10mt* for which this value decreases to 29% (See Appendix D). If we neglect these two exceptions, percentage contributions of the model variables can be classified as satisfactory.

Now, further comparisons will be made between the games played by two scuba divers who have similar scuba diving experience. The output behaviors obtained in high pace, high flow volume and without delay game can be seen in Figure 5.4. It was subject 12's second trial and subject 15's 4$^{th}$ trial. Subject 12 tried to control not only the depth but also the speed from the beginning of the game. It took longer to reach 10 meters but as she reached, it was easy to stabilize since speed was low. Subject 15 also tried to control speed together with depth but enough importance was not given to control the speed. Since she reached 10 meters with a higher speed, she experienced larger amplitude of oscillations.

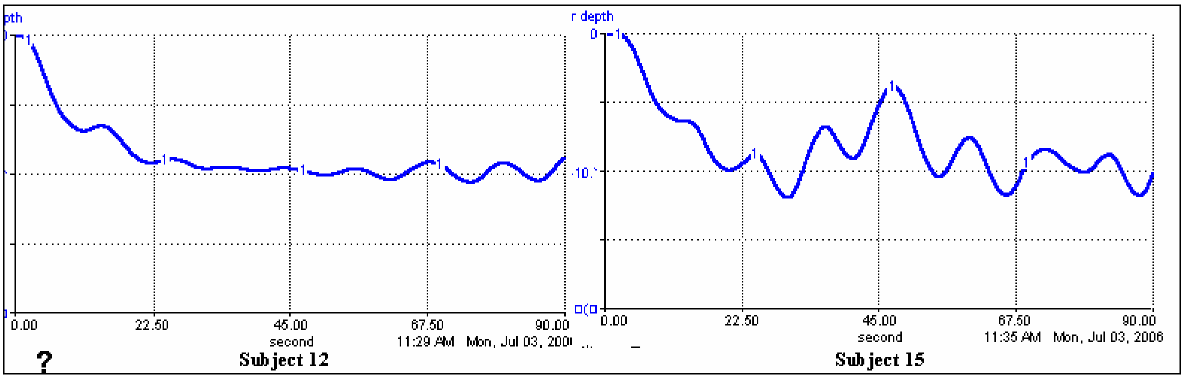



Figure 5.4. Output behaviors obtained by subject 12 and subject 15 in game type 6

Although subjects have similar backgrounds, their strategies and performances differ. The same conclusion can be also made for system dynamics knowledge. Thus, differences in performance can not be established at group level but in individual level.

### 5.3. Comparison Between Two Game Versions

Although there are differences between games initialized at surface and 10 meters, some performance measures utilized for both games and some performance measures can be equilibrated. As the scores obtained in these two experimental settings are used in a Latin square design with two replicates, more accurate results can be obtained.

*Max-dev-10, max-amp-osc* and *dev-mean-10mt* performance measures are utilized in both experimental settings. Thus, these scores will be directly used. However, *amp-of-fluct* and *dev-area-mean* performance measures, utilized in games initialized at 10 meters, should be averaged to make a comparison with *time average of amp-of-fluct* and *time average of dev-area-mean* performance measures used in games initialized at surface. Thus, the first two performance measures are divided by 85 which is the length of simulation after disturbance in games initialized at 10 meters.

Before presenting analysis of variance, model assumptions are checked. For *time average of Dev-area-mean* and *max-amp-osc* there are significant violations of equality of variance and normality assumption. Thus, transformation of variables is applied for these two performance measures. After natural logarithmic transformation, it is observed that there is not any significant violation of model assumptions.

Table 5.12. ANOVA table for Latin square experiments for games initialized at 10 meters and at surface (log transformed data for *time average dev-area-mean* and *max-amp osc*)

| | | | Time average of deviation area from mean | | Time average of total amplitude of fluctuations | | Maximum deviation from 10 meters | | Maximum amplitude of oscillations | | Deviation of mean from 10 meters | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source of Variation | | DoF | SS | P Value | SS | P Value | SS | P Value | SS | P Value | SS | P Value |
| Game Type-Total | | 7 | 23 | 0 | 1 | 0 | 211 | 0 | 13 | 0 | 11 | 0.01 |
| Game Type | Game Speed | 1 | 1 | 0.02 | 0 | 0 | 31 | 0.01 | 2 | 0.01 | 1 | 0.22 |
| | Delay | 1 | 20 | 0 | 1 | 0 | 154 | 0 | 10 | 0 | 10 | 0 |
| | Flow Volume | 1 | 1 | 0.04 | 0 | 0 | 0 | 0.92 | 0 | 0.57 | 0 | 0.88 |
| | Game Speed x Delay | 1 | 0 | 0.46 | 0 | 0.59 | 3 | 0.39 | 0 | 0.78 | 1 | 0.26 |
| | Game Speed x Flow Volume | 1 | 0 | 0.45 | 0 | 0.04 | 0 | 0.75 | 0 | 0.83 | 0 | 0.5 |
| | Delay x Flow Volume | 1 | 0 | 0.48 | 0 | 0.34 | 21 | 0.03 | 1 | 0.08 | 0 | 0.94 |
| | Game Speed x Delay x Flow Volume | 1 | 0 | 0.54 | 0 | 0.42 | 1 | 0.65 | 0 | 0.56 | 0 | 0.96 |
| Subject | | 14 | 16 | 0 | 2 | 0 | 214 | 0 | 13 | 0 | 14 | 0.04 |
| Practice | | 7 | 4 | 0.01 | 0 | 0 | 107 | 0 | 5 | 0 | 1 | 0.92 |
| Game Version | | 1 | 1 | 0.06 | 0 | 0.03 | 0 | 0.9 | 0 | 0.91 | 1 | 0.32 |
| Error | | 98 | 22 | | 1 | | 442 | | 21 | | 53 | |
| Total | | 127 | 66 | | 4 | | 974 | | 51 | | 81 | |

As seen in Table 5.12, total variation that is explained by model variables is between 54% and 75% except *dev-mean-10mt* for which it is 34%. Percentage variability for each performance measure that can be explained by model parameters seems to be adequate except *dev-mean-10mt*.

Table 5.13. Distribution of scores with respect to game versions

| | Total score in games initialized at | |
|---|---|---|
| | 10 meters | Surface |
| Time average of deviation area from mean | 111.47 | 95.07 |
| Time average of amp-of-fluct | 22.97 | 25.64 |
| Maximum deviation from 10 meters | 315.8 | 318.82 |
| Maximum amplitude of oscillations | 463.34 | 453.04 |
| Deviation of mean from 10 meters | 48.49 | 40.15 |

As seen in Table 5.12, there are statistically significant differences between scores obtained in games initialized at 10 meters and surface with respect to *time average of dev-area-mean* and *time average of amp-of-fluct*. However, additional differences between these two games can not be detected with respect to other performance measures. Table 5.13 shows the total scores obtained in these two games. Subjects are found to be more successful in surface games with respect to time average of dev-10-mt, however they found to be less successful with respect to time average of amp-of-fluct.

Continuing with practice throughout trials, it is seen that total scores in at least one trial is significantly different than others with respect to all performance measures but *dev-mean-10mt.* Total scores obtained at each trial can be seen in Table 5.14. Although, score obtained in first trial is significantly poorer than others, similar conclusions can not be made between each consecutive trial. There are improvement and deteriorations throughout trials.

Table 5.14. Total scores obtained at each trial from both game versions

| | Time average of deviation area from mean | Time average of amp-of-fluct | Maximum deviation from 10 meters | Maximum amplitude of oscillations | Deviation of mean from 10 meters |
|---|---|---|---|---|---|
| Trial1 | 35.11 | 7.55 | 104.39 | 148.18 | 13.89 |
| Trial2 | 25.37 | 5.86 | 78.92 | 117.38 | 11.35 |
| Trial3 | 29.6 | 6.45 | 98.24 | 142.33 | 11.23 |
| Trial4 | 22.15 | 5.59 | 75 | 99.74 | 12.01 |
| Trial5 | 25.47 | 6.55 | 77.41 | 115.37 | 9.7 |
| Trial6 | 29.87 | 6.29 | 79.6 | 110.19 | 12.3 |
| Trial7 | 20.22 | 5.34 | 61.69 | 96.99 | 10.07 |
| Trial8 | 18.75 | 4.98 | 59.37 | 86.19 | 8.1 |

Additionally, performance is significantly affected by game attributes; game speed, delays and air flow volume. For games initialized at 10 meters, game speed is found to be significantly effective on performance with respect to *dev-area-mean, amp-of-fluct and max-amp-osc* within these five performance measures. On the other hand, for games initialized at surface, game speed is effective with respect to all these five performance measures but *dev-mean-10mt*. When these two sets of data are utilized, it is found that game speed is effective with respect to all performance measures but *dev-mean-10mt* performance measure. When we analyzed the effect of game speed, it is seen that high game speed deteriorates performance. However, some subjects found high game speed games more realistic and also most of the subjects stated that difficulties are not due to game speed.

In both games, initialized at 10 meters and at surface, delay is found the most effective on performance. The same result is also obtained in this analysis. Thus, this effect must be investigated intensely. Information and material delay will be analyzed separately in the following analysis. Flow volume is also effective on performance with respect to *time average of dev-area-mean* and *amp-of-fluct*. As seen in Table 5.15 high flow volume deteriorates performance with respect to *time average of amp-of-fluct* but improves performance with respect to *time average of dev-area-mean*. With high flow volume, subjects might change their direction easily and rapidly, so that their deviation from the target value is not high as much as low flow volume. However, this rapid direction change is followed by another rapid direction change which results in high score with respect to *time average of amp-of-fluct*.

Table 5.15. Contrast values obtained in Latin square experiments for both game versions

| | Time average of deviation area from mean | | Time average of total amplitude of fluctuations | | Maximum deviation from 10 meters | | Maximum amplitude of oscillations | | Deviation of mean from 10 meters | |
|---|---|---|---|---|---|---|---|---|---|---|
| | low | high | low | high | low | high | low | high | low | high |
| Game Speed | 95 | 112 | 21 | 27 | 286 | 349 | 415 | 501 | 39 | 49 |
| Delay | 70 | 136 | 19 | 29 | 247 | 387 | 356 | 560 | 27 | 62 |
| Flow Volume | 115 | 92 | 22 | 27 | 318 | 316 | 482 | 434 | 44 | 45 |
| Game Speed x Delay | 103 | 103 | 25 | 24 | 307 | 328 | 448 | 468 | 40 | 49 |
| Game Speed x Flow Volume | 102 | 105 | 23 | 26 | 314 | 321 | 457 | 459 | 42 | 47 |
| Delay x Flow Volume | 109 | 98 | 24 | 25 | 343 | 292 | 494 | 423 | 44 | 45 |
| Game Speed x Delay x Flow Volume | 98 | 108 | 24 | 25 | 312 | 323 | 446 | 471 | 44 | 45 |

Additionally, game speed- flow volume interaction effect is found to be effective on performance with respect to *time average of amp-of-fluct*. Relationship is very similar to the relation obtained in games initialized at 10 meters (See Figure 5.2).

## 5.4. Conclusion for Latin Square Experiments

Latin square experiments are divided into two groups, 10 meters and surface games, depending on the initial position. Individual analysis is carried out in these two game versions. Then, combined game results are utilized in Latin Square design with two replications to compare the two game versions.

Statistical results are summarized in Table 5.16. *Dev-10-mt*, *amp-of-fluct* and *max-dev-10* performance measures are used in games initialized both at 10 meters and at surface. ±2 *settling time* is the last primary measure for games initialized at 10 meters whereas *deviation from 10 meters in first oscillation* is the last primary measure for games initialized at surface. However, since none of the effects is significant with respect to *deviation from 10 meters in first oscillation* measure, conclusions will ignore the *deviation from 10 meters in first oscillation* measure.

Table 5.16. Significance of game attributes, subject and practice effects in Latin Square experiments: primary performance measures

| Source of variation | Time average /Deviation area from 10 mt | Time average /Total amplitude of fluctuations | Maximum deviation from 10 mt | (for games initialized at 10 mt) |
|---|---|---|---|---|
| Game Type-Total | significant | significant | significant | significant |
| Game Speed | significant | significant | significant only for surface games | significant |
| Delay | significant | significant | significant | significant |
| Flow Volume | significant only for surface games | significant | not significant | not significant |
| Game Speed x Flow Volume | not significant | significant only for 10 mt games | significant only for 10 mt games | significant |
| Delay x Flow Volume | not significant | not significant | significant only for surface games | not significant |
| Game Speed x Delay x Flow Volume | not significant | significant only for 10 mt games | significant only for 10 mt games | not significant |
| Subject | significant | significant | significant | significant |
| Practice | significant only for 10 mt games | significant only for 10 mt games | significant only for 10 mt games | significant |

As the significance of game attributes, subject and practice effects are tested, it is seen that significance conclusions can be different with respect to different performance measures. In ScubaSim, different aspects of stability are measured by various performance measures (See Section 4.6). To explain with an example, flow volume is significantly effective on stability if *amp-of-fluct* measure is used. However, flow volume has insignificant effect on stability if *max-dev-10* measure is used. In other words, sum of amplitude of fluctuations differs significantly under low and high flow volume. However, maximum deviation from desired depth is not affected by the level of flow volume. On the other hand, existence of delays significantly affects stability with respect to all measures. While flow volume can affect some aspects of stability, delays affect all aspects of stability.

For games initialized at surface, practice effect is not significant. But practice effect is found significant for games starting at 10 meters. Thus, score obtained at least in one trial is statistically different than other trials. Although there is not a continuous improvement through trials, significant improvements and deteriorations are observed between trials. This result can be explained with the following factors. First, there is no replication in the design; with replications, more accurate results will be obtained. Second, there may be fatigue effect in later trials, subjects may get bored or become tired after a few trials. Lastly, it may not be possible to alter strategy between successive trials.

Continuing with the subject effect, it is found significant for both game versions. In each version, score obtained by at least one subject differs from scores obtained by other subjects. Thus, blocking should be used in statistical analysis where experiments are carried out with different subjects.

Lastly, effects of game attributes on performance will be summarized. Game speed, delay and flow volume and their interaction effects are tested for significance. Game speed is found effective for all primary performance measures and game versions except *max-dev-10* for games initialized at 10 meters. Performance is deteriorated due to time pressure when game speed is increased. Although the game speed is found significantly effective on performance, delays are more effective than the game speed. In Latin Square experiments, length of delay is constant and 1 seconds. In delay condition, both material delay and information delay exist. Existence of both delays and long delay times have negative effect on performance. Thus, in second part of research, effects of material delay and information delay will be investigated individually. The last attribute, flow volume is found significant in both games with respect to *amp-of-fluct* measure and only in surface games with respect to *dev-10-mt* measure. (Game speed) x (flow volume) interaction effect is found significant only for games initialized at 10 meters all primary performance measures except *dev-10-mt.* (Delay) x (flow volume) interaction effect is significant only for surface game with respect to *max-dev-10* measure. The three way interaction effect, (game speed) x (delay) x (flow volume) is also found to be significant in games initialized at 10 meters with respect to *amp-of-fluct* and *max-dev-10* measures.

# 6. RESULTS OF REPEATED MEASURES EXPERIMENTS

In Latin square design, when there is a delay in the game, both delays exist. We are not able to differentiate effects of individual delays: information or material. Additionally, there may be an interaction effect such that the output behavior is deteriorated with existence of both delays. So, the effects of material and information delay must also be analyzed separately. For this analysis, 4 different game structures are used depending on material and information delays. In no delay game, neither material nor information delay exists. In the second type of game, material delay is added to basic structure. In the third type of game, only information delay is added. And, in the last game both information and material delays are added to basic structure. The average length of each delay in the model is 0.5 seconds, modeled as continuous exponential delay.

Table 6.1. Allocation of subjects to game types

| Game Type | No Delay | | | | | Material Delay | | | | | Information Delay | | | | | Both Delays | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject number | S 17 | S 18 | ... | S 23 | S 24 | S 25 | S 26 | ... | S 31 | S 32 | S 33 | S 34 | ... | S 39 | S 40 | S 41 | S 42 | ... | S 46 |
| Trial 1 | | | | | | | | | | | | | | | | | | | |
| Trial 2 | | | | | | | | | | | | | | | | | | | |
| Trial 3 | | | | | | | | | | | | | | | | | | | |
| Trial 4 | | | | | | | | | | | | | | | | | | | |
| Trial 5 | | | | | | | | | | | | | | | | | | | |
| Trial 6 | | | | | | | | | | | | | | | | | | | |

Allocation of subjects to game types can be seen in Table 6.1. As seen, each subject played the assigned game six times, all of which are played in one session. None of the subjects has scuba diving experience.

The differences between subjects and differences between trials are tested for each of these four game types. No delay game is compared with material delay game to test the effect of material delay. Then, no delay game is compared with information delay game to evaluate the effect of information delay. Next, no delay, material delay and information delay games are compared with each other. And finally, all four games are compared to assess effects of material and information delay and interaction effect of these delays. In the comparison, firstly each subject's data are taken as a replication. And then, analysis is repeated with each subject taken as a separate block. If there are differences between subjects, results will be clearer when subjects are taken as blocks.

Table 6.2. Allocation of subjects to game with and without pause option

| | Both delays present | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Game Type | Without Pause Option | | | | | | With Pause Option | | | | | | |
| Subject number | S 41 | S 42 | S 43 | S 44 | S 45 | S 46 | S 47 | S 48 | S 49 | S 50 | S 51 | S 52 | S 53 |
| Trial 1 | | | | | | | | | | | | | |
| Trial 2 | | | | | | | | | | | | | |
| Trial 3 | | | | | | | | | | | | | |
| Trial 4 | | | | | | | | | | | | | |
| Trial 5 | | | | | | | | | | | | | |
| Trial 6 | | | | | | | | | | | | | |

In Latin square design, for some performance measures, no significant difference is found between fast and slow games. To investigate further, an extreme case of game speed, pause option is presented to the subjects. By using pause button, subjects can stop the game and use time as much as they want. Since, time pressure becomes critical with increased game complexity, pause option is presented only in games involving both delays. The results are compared to evaluate the effect of time pressure, i.e. pause option. The experimental design can be seen in Table 6.2.

Table 6.3. Allocation of scuba divers and non scuba divers to no delay game

| | No Delay | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Game Type | No diving experience | | | | | Scuba Divers | | | |
| Subject number | S 17 | S 18 | …. | S 23 | S 24 | S 54 | S 55 | …. | S 59 |
| Trial 1 | | | | | | | | | |
| Trial 2 | | | | | | | | | |
| Trial 3 | | | | | | | | | |
| Trial 4 | | | | | | | | | |
| Trial 5 | | | | | | | | | |
| Trial 6 | | | | | | | | | |

In Latin square games, although scuba divers are randomly assigned, it is observed that their initial games were mostly the games without delay. There may be some bias such that scuba divers learnt in the absence of delays, hence became successful, whereas non scuba divers faced delay games in their first trials and were not able to understand dynamics and true effects of their control actions. For this reason, these two groups are later compared under the same situation. Scuba divers played no delay game and their performances are compared with the results of subjects without scuba diving experience. The experimental design can be seen in Table 6.3.

## 6.1. Individual Analysis for Each Type of Game

In this part of the thesis, analysis within each game type is conducted where essentially practice effect and differences between subjects are investigated. The Design Expert statistical software is utilized for the two successive analyses. In the first step, 2 factor multi-level statistical analysis is conducted. The two factors are practice and subject. Since there is no replication for subjects, (subject) x (practice) interaction effect is taken into the lack of fit. In all games, differences between subjects are found to be significant. Thus, in the consecutive analysis, each subject is modeled as a separate block.

If there was no significant difference between subjects, then each subject would be modeled as a replication. On the other hand, since significant differences between subjects are found, each subject is modeled as a separate block which decreases the degrees of freedom. It is hypothesized that subjects' performances will improve over the trials. Although improvement patterns might be different for different game types, practice effect may be significant. The results will be discussed in the following sections, individually for each game type.

### 6.1.1. No Delay

No delay game is played by eight subjects and each subject played the same game six times. The subjects are graduate students; two of them are girls.

Figure 6.1 shows two output behaviors obtained in no delay game by subject 23 in the second and the sixth trials. In the second trial, subject experiences higher amplitude of oscillations. Under same conditions, subject plays four more games after that second trial. The last, sixth trial, can be seen in the right part of Figure 6.1. The amplitude of oscillations decreases significantly and control is preserved throughout the game. Thus, this behavior difference gives an idea about the practice effect where practice increases performance and controllability in this dynamic decision game environment. The output behaviors obtained in no delay game by subjects 17-24 can be seen in Appendix F.

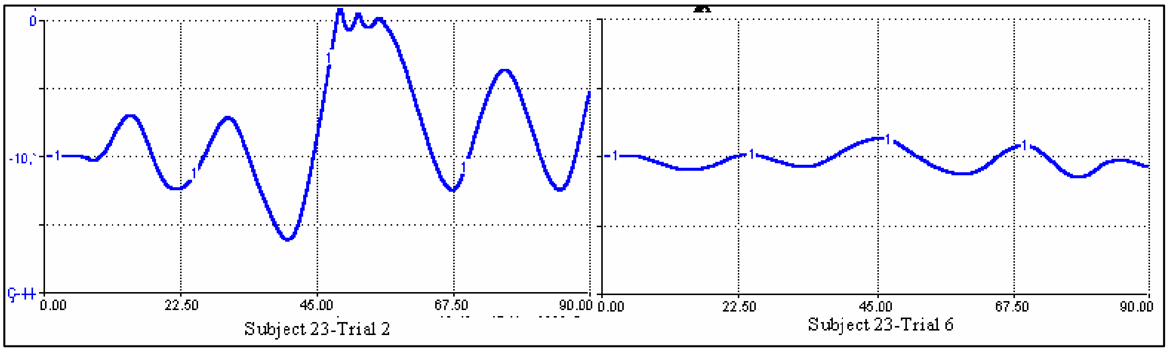



Figure 6.1. Typical results obtained in no delay game

*Dev-10-mt* performance measure for each subject can be seen in Figure 6.2. As seen, there are significant differences between subjects' performances. Additionally, performance in the first two trials is significantly worse than remaining trials. Initially, performances obtained by subjects varied much, but their performances settled down to the range (50,150) after two trials. Additionally, subjects can be divided into two groups. Subject 17, 19, 22 and 24 were successful from the first trial and they preserved that level of success through the six trials. On the other hand, subjects 18, 20, 21 and 23 performed worse than other subjects in the first two trials, but a significant improvement is observed at third trials. Their performances almost became as good as subjects in the first group. Thus, we can conclude that some subjects initially formed and utilized a good heuristic for control whereas others changed their strategies with experience and improved their performances. Two subjects in the second group, subjects 18 and 23, declared a strategy change in the post game questionnaire. Subject 23 stated that she eventually tried to achieve the smallest slope as soon as possible whereas her initial strategy was to change inflating (deflating) decision to deflating (inflating) approximately at local extremes. However, other subjects did not clearly declare a strategy change. They may have made small changes in their strategies and they may not be aware that they changed their strategies.

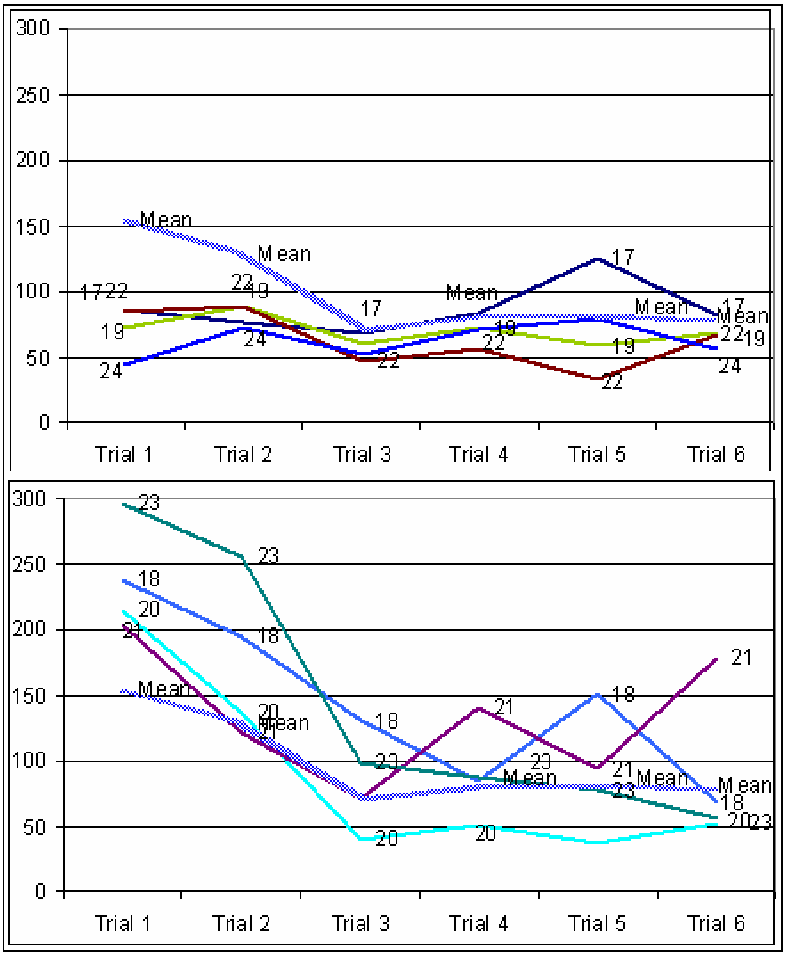



Figure 6.2. Scores obtained in no delay game by subjects 17-24: *dev-10-mt*

With analysis of variance, significance of subject and practice effects is tested. In the first analysis, each subject is taken as an effect. Thus, experimental design is 2 factor experimental analysis, where subject effect has 8 levels and practice effect has 6 levels. With this analysis of variance, P values in Table 6.4 are obtained for primary performance measures whereas results of secondary performance measures can be seen in Appendix E. As seen, for all performance measures practice and subject effects are found to be significant.

After validating that there are significant differences between subjects, blocking is used for subjects. In the second analysis, one factor with blocking experimental design is utilized. Same P values are obtained for practice effect (See Table 6.4). In both experimental designs, it is seen that normality assumption is satisfied and there is not any outlier in the data set.

Table 6.4. Percentage contribution and P values of subject and practice effect in no delay game for primary performance measures

| Source of Variation | | Deviation Area from 10 meters | Total Amplitude of Fluctuations | Maximum Deviation from 10 meters | ±2 Settling Time |
|---|---|---|---|---|---|
| Practice | Percentage Contribution | 0,3965 | 0,4999 | 0,3352 | 0,3670 |
| | P Value | 0.0025 | 0.0001 | 0.0109 | 0.0052 |
| Subject | P Value | 0.0032 | < 0.0001 | 0.0002 | 0.0224 |

In the previous two experimental designs it is validated that there are differences between trials but further investigation should be done to decide whether there is improvement throughout trials (See Figure 6.3).

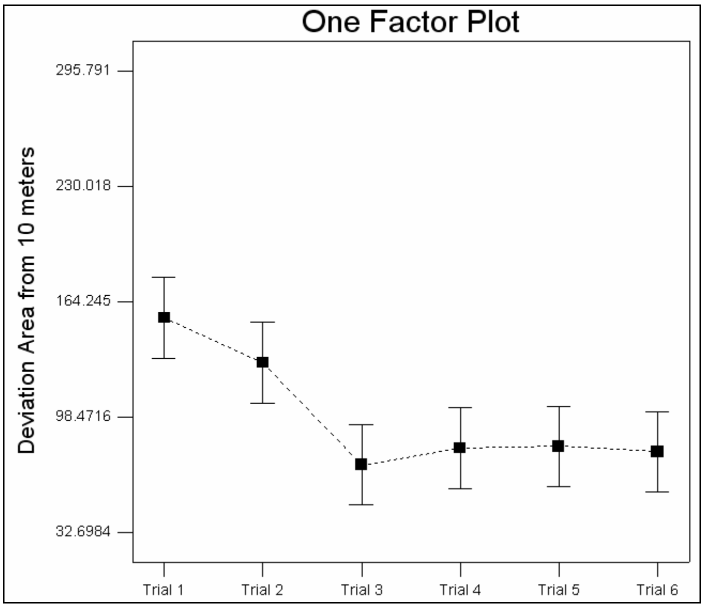



Figure 6.3. Mean scores in no delay game: *dev-10-mt*

For statistical significance, differences between mean values are tested (See Table 6.5). Trial 1 is found to be significantly different than all trials but trial 2. Additionally, trial 2 is also found to be significantly different than all other trials but trial 1. Moreover, there is not enough evidence to conclude that remaining four trials are different than each other. To sum up, there are two significant levels of performance throughout the game. Subjects' performances are poor in the first two trials, and an improvement is observed after these two trials. But further improvement is not seen after the third trial, in other words performance is not changed significantly.

Table 6.5. Pair-wise comparisons of trials: *dev-10-mt* measure

| Treatment | 1vs2 | 1vs3 | 1vs4 | 1vs5 | 1vs6 | 2vs3 | 2vs4 | 2vs5 | 2vs6 | 3vs4 | 3vs5 | 3vs6 | 4vs5 | 4vs6 | 5vs6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prob > \|t\| | 0.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.04 | 0.04 | 0.03 | 0.68 | 0.64 | 0.74 | 0.96 | 0.93 | 0.89 |

Table 6.6. Estimated mean values in each trial: *dev-10-mt* measure

| Trial # | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|---|---|---|---|---|---|---|
| Estimated Mean | 154,89 | 129,33 | 71,10 | 80,62 | 81,65 | 78,56 |

### 6.1.2. Material Delay

The performances of eight subjects in the game with material delay are firstly used for visual analysis of output data and then statistical analysis is made for investigating significance of differences between subjects and between trials. For the visual analysis, *dev-10-mt* measure is selected (See Figure 6.4).

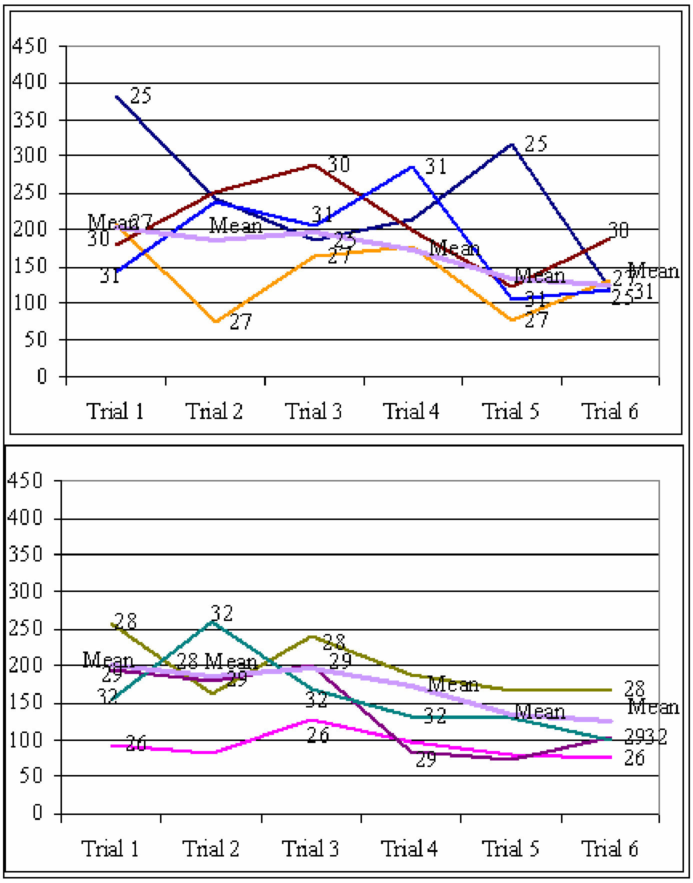



Figure 6.4. Scores obtained in material delay game by subjects 25-32: *dev-10-mt*

At first glance, a trend throughout trials can not be observed. There are minor differences between trials. Subject 26's performance remains the same all over the trials. His performance is really satisfactory from the first trial and he preserves his performance. Subject 29 has similar results in her first three trials, but at the 4th trial performance is significantly improved and stayed at that performance level in the following two trials. For the other six subjects, it is not possible to conclude significant improvement or deterioration, their mean scores stays the same all over the trials but a high variability is observed in scores.

Figure 6.4 shows significant differences between subjects but a significant difference between trials is not observed. This can be explained by the negative effect of delays. In the literature, it is stated that existence of delays weakens the feedback obtained from system. Although existence of delays is known by subjects, satisfactory strategies may not be developed to deal with delays (Brehmer, 1995).

Another observation is about the variance throughout the trials. The variance of scores is nearly the same in these six trials. When compared to no delay games, the variance is found to be larger in material delay games. Differences between subjects or strategies result in diverse behaviors.

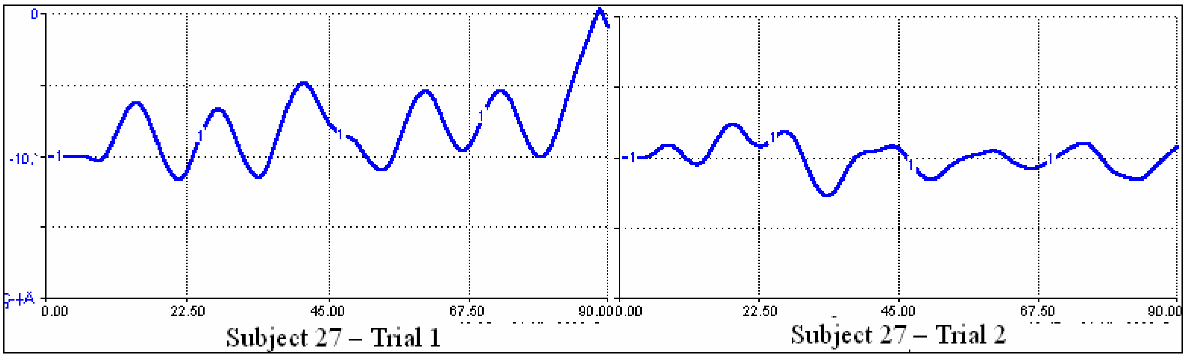



Figure 6.5. Typical results obtained in material delay games

Figure 6.5 shows two typical output behaviors observed in material delay games. These two games are played by the same subject, Subject 27. In the fist trial, almost constant amplitude of oscillations is observed. However, subject managed to control the system in the second trial. All results obtained in material delay games can be seen in

Appendix F (Subject 25-32). When behaviors are examined, it is seen that performance is worse in material delay games. However, improvement is observed throughout trials; amplitude of oscillations decreases, mean depth value converges to desired depth.

As previously explained, 48 data points for material delay games are analyzed. When normality assumption is checked, normal probability plot of residuals seems adequate. The distributions of residuals over the predicted values and over practice effect are constant. Thus, it is concluded that normality assumption is satisfied.

In the fist step of experimental analysis, significance between subjects is questioned and depending on the results of the first analysis, it is decided to use or not to use blocking for each subject. As seen in Table 6.7, there are statistically significant differences between subjects for all performance measures.

Table 6.7. Percentage contribution and P values of subject and practice effect in material delay game

| | | Deviation Area from 10 meters | Total Amplitude of Fluctuations | Maximum Deviation from 10 meters | ±2 Settling Time |
|---|---|---|---|---|---|
| | Percentage Contribution | 0,2932 | 0,4594 | 0,2813 | 0,1700 |
| Practice | P-Value | 0.027 | 0.0004 | 0.0343 | 0.2366 |
| Subject | P-Value | 0.001 | < 0.0001 | 0.0392 | 0.0101 |

After validating that there are significant differences between subjects, subjects modeled as separate blocks in the successive experimental analysis. The P-values and percentage variation explained by practice effect for each primary performance measure can be seen in Table 6.7. There are significant differences between trials for all performance measures but ± 2 settling time. Due to nature of the game, small errors or loss of attention may result poor output behaviors. In the existence of material delay, tiny differences in deflating/inflating decisions may result in the diver to go outside the range 8-12 meters. So, this may be the cause for having insignificant differences between trials for ± 2 settling time performance measure.

When pair-wise comparisons between trial means are made, it is observed that performances in trial 1, 2, 3 and 4 are significantly worse than other trials (See Table 6.8).

There are two different levels of performance. In the first four trials, performance remained in the same levels. However at 5th trial an improvement observed and this level of performance is preserved in the 6th trial.

Table 6.8. Pair-wise comparison of trials in material delay game: *dev-10-mt*

| Treatment | 1vs2 | 1vs3 | 1vs4 | 1vs5 | 1vs6 | 2vs3 | 2vs4 | 2vs5 | 2vs6 | 3vs4 | 3vs5 | 3vs6 | 4vs5 | 4vs6 | 5vs6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prob > ltl | 0.58 | 0.87 | 0.29 | 0.02 | 0.01 | 0.69 | 0.6 | 0.06 | 0.03 | 0.36 | 0.02 | 0.01 | 0.16 | 0.09 | 0.77 |

Table 6.9. Mean scores obtained in material delay game: *dev-10-mt*

| Trial # | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|---|---|---|---|---|---|---|
| Estimated Mean | 202 | 186 | 197 | 172 | 133 | 125 |

### 6.1.3. Information Delay

Information delay structure is added to basic structure to investigate the effect of information delay on performance. Two typical game results are presented in Figure 6.6. Although these outputs are obtained by Subject 35, similar behaviors are observed in games played by other subjects. As will be seen in Figure 6.6 and Appendix F, initially control is very poor compared to no delay game. Most subjects managed to improve their performance and decreased amplitude of oscillations, but performances are still poorer compared to no delay games at the end of sixth trial. Another comparison can be made with material delay games: Although both material and information games have the same amount of delay, performance was poorer in information delay games in first trials. However, subjects are able to develop better strategies and performed as good as subjects played in material delay games in later trials.

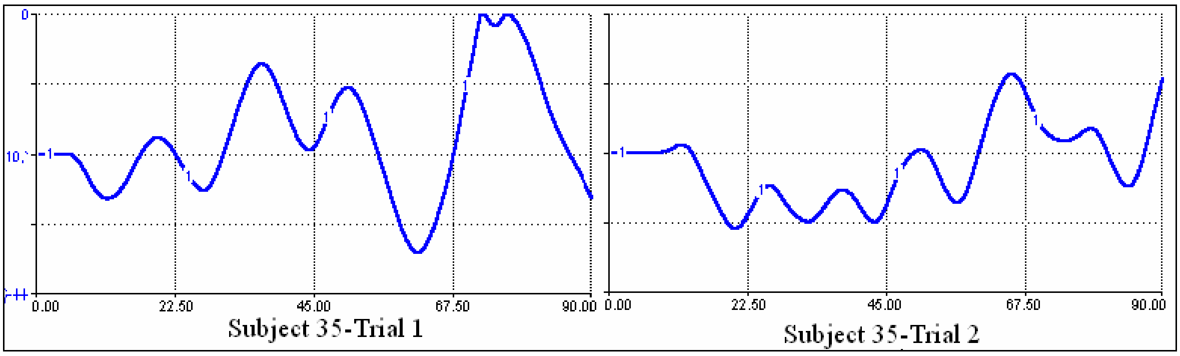



Figure 6.6. Typical results obtained in information delay games

The game results of eight subjects who played games with information delay are firstly utilized to see whether there are differences between subjects and whether performance is improved with practice. Subjects' scores in *dev-10-mt* performance measure are shown have insight about data (See Figure 6.7). Scores in first trial varies between 180 and 500 where subject 39 had the lowest score and can be seen as an outlier when scores of other subjects investigated. All subjects except subject 40 improved their performances in second trial. Especially subject 36, who had the highest score initially, had the lowest score in the second trial. She declared that in her first trial she tried to learn the effect of her decisions and her poor performance in her first trial depends on that reason. Also, it is seen that her subsequent scores are close to score in her second trial. As observed from mean scores of subjects, there is an improvement between 1st and 2nd trials but in the following four trials no further improvement is observed. The same observation may be done for individual subjects; improvement is observed between 1st and 2nd trials but in the subsequent four trials there are improvements and deteriorations.

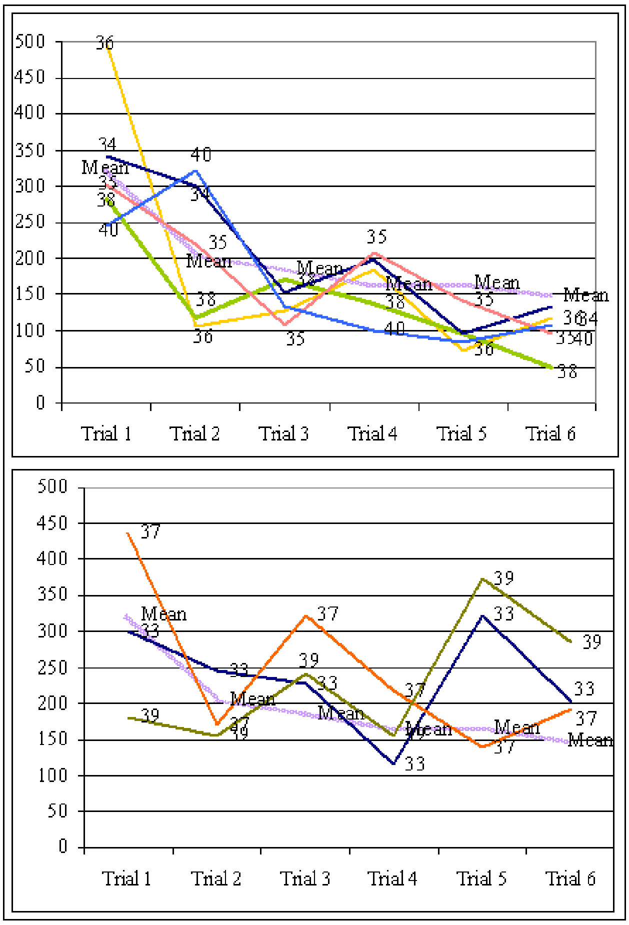



Figure 6.7. Scores obtained in information delay game by subjects 33-40: *dev-10-mt*

As seen in Figure 6.7, subjects can be divided into two groups. In the first group, subjects usually improved their performance when compared to preceding trials they had. However, in the second group, subjects experienced significant improvements which followed with significant deteriorations. In other words, continuous improvement is not observed. Additionally, their scores stayed above the mean score which shows that they performed worse than average.

Table 6.10. Percentage contribution and P values of subject and practice effect in information delay game for primary measures

| | | Deviation Area from 10 meters | Total Amplitude of Fluctuations | Maximum Deviation from 10 meters | ±2 Settling Time |
|---|---|---|---|---|---|
| Practice | Percentage Contribution | 0,4035 | 0,4638 | 0,3526 | 0,1627 |
| | P-Value | 0.0021 | 0.0004 | 0.0073 | 0.2628 |
| Subject | P-Value | 0.3382 | 0.0155 | 0.0237 | 0.2861 |

After visual analysis of game results, statistical analysis is done. Subject effect is found significant for *amp-of-fluct, max-dev-10* and *max-amp-osc* performance measure. However for the remaining performance measures, there is not enough evidence to conclude that subjects differ. At the next step, subjects are modeled as separate blocks in the following analysis. In Table 6.10, P-values and percentage contribution can be seen for primary performance measures (See Appendix E for secondary performance measures).

For all performance measures except ±2 settling time, practice effect is significant. When scores obtained in ±2 settling time performance measure examined, it is observed that subjects mostly got 90 in their trials meaning that at the end of game they are not in the range 8-12 meters. Thus, performance of subjects is not significantly different with respect to that score.

When we check normality assumption, it seems satisfactory for all performance measures however there is a mild violation in variation of residuals with respect to practice. Variation decreases with more practice. Additionally, there is an outlier with respect to ± 2 settling time performance measure. The outlier data point belongs to subject 38's last trial. He is able to settle down at t=38.45. The performance is so superior that it became an outlier. However, violation is not severe so that the results of analysis are decided to be valid.

Table 6.11. Pair-wise comparison of trials in information delay game: *dev-10-mt*

| Treatment | 1vs2 | 1vs3 | 1vs4 | 1vs5 | 1vs6 | 2vs3 | 2vs4 | 2vs5 | 2vs6 | 3vs4 | 3vs5 | 3vs6 | 4vs5 | 4vs6 | 5vs6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prob > \|t\| | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.65 | 0.34 | 0.36 | 0.19 | 0.61 | 0.63 | 0.38 | 0.98 | 0.70 | 0.68 |

Next analysis is done to find qualitative and quantitative properties of practice effect. In Table 6.12, estimated mean scores for dev-10-mt performance score can be seen. The significance of difference of two consecutive trials can be seen in Table 6.11. It is observed that trial 1 is statistically significantly different and worse than other trials, but the remaining trials are not statistically different from each other.

Table 6.12. Mean scores obtained in information delay game: *dev-10-mt*

| Trial # | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|---|---|---|---|---|---|---|
| Estimated Mean | 323 | 204 | 186 | 164 | 166 | 148 |

### 6.1.4. Both-Delays

The data obtained in existence of both material and information delay is utilized for questioning significant differences between subjects and between trials. After visual analysis of game results, statistical analysis will be shown for testing these two differences. It is expected that the control of the system will become difficult in the existence of both delays. The variances between subjects and between trials may be larger than the ones observed in other games, since minor differences in decisions will result in different output behaviors due to material and information delays.

Two typical game results can be seen in Figure 6.8. The two games played by Subject 46. In the first trial, deviation from desired depth is very high and four large oscillations are observed. Since both information and material delay exists in the structure, subjects are not able to control the system effectively. However, performance improvement is observed (See Figure 6.8 and Appendix F). In the last trial, Subject 46 performs satisfactorily. Although oscillations are observed, their amplitudes are significantly decreased and mean depth value converges to the desired one, 10 meters. When comparison made with material and information delay games, it is seen that deviations are larger in both-delays games and performance improvement is observed in later trials. In other words, subjects played in both-delay games need more practice to apprehend the situation and/or develop better strategies.

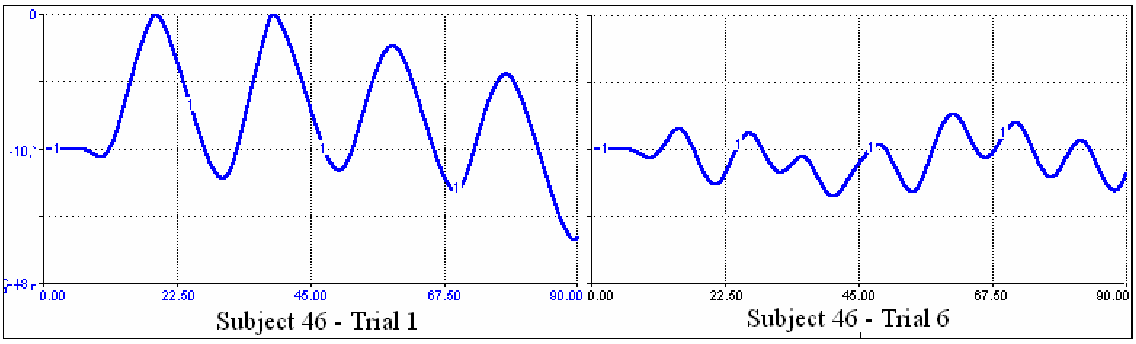



Figure 6.8. Typical results obtained in both-delays game

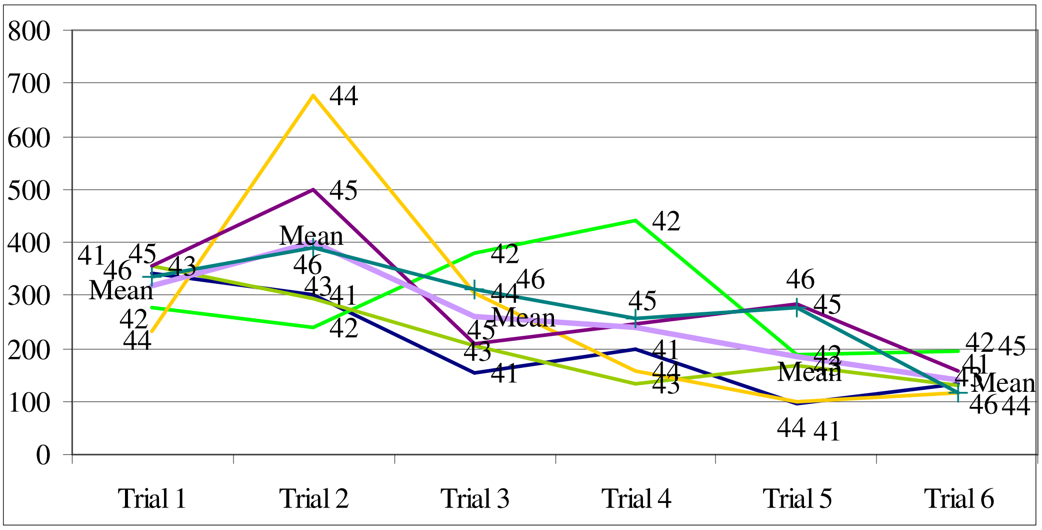



Figure 6.9. Scores obtained in both-delays game by subjects 41-46: *dev-10-mt*

Figure 6.9 shows the results obtained by six subjects at each six trials with respect to *dev-10-mt* performance measure. When the general trend over the trials is investigated, it is seen that there is a decreasing trend with respect to the performance measure meaning performance improvement throughout trials. But there are two exceptions; subject 42 and subject 44. Starting with subject 42, she had better results than average of subjects in the first two trials. But performance deteriorated without any solid reason. She later wrote that she gave false decisions in the 3rd and 4th trials. In the last two trials, it is seen that performance improved again. The similar variations are also observed in other subjects' performances throughout the trials. The reason for this variation may be attributed to the sensitiveness of the output behavior in the existence of delays. Subject 42's results are not seen as an outlier.

Unlike subject 42, subject 44's second trial can be seen as an outlier. In the first and third trials, he got scores between 200 and 300 but in his second trial he got nearly 700. Such a large score is not obtained in any other trials of five subjects in games with both delays. Subject did not declare anything about that trial. The results of statistical analysis should be utilized for final decision about subject 44's second trial.

For *dev-10-mt* and *dev-mean-10mt*, subject 44's second trial and for ±2 *settling time*, subject 44's 3rd trial are found to be outliers. When the output behaviors are examined, trial 2 is problematic whereas trial 3 is normal. Thus, only trial 2 is categorized as an outlier. Table 6.13 is obtained from statistical analysis. There are statistically significant differences between subjects and between trials with respect to some performance measures. Before making final conclusion, outlier should be investigated.

Table 6.13. Percentage contribution and P values of subject and practice effect in both-delays game for primary performance measures

| | Source of Variation | | Deviation Area from 10 meters | Total Amplitude of Fluctuations | Maximum Deviation from 10 meters | ±2 Settling Time |
|---|---|---|---|---|---|---|
| Original Data | Practice | Percentage Contribution | 0,5198 | 0,5569 | 0,6177 | 0,1666 |
| | | P Value | 0.0017 | 0.0007 | 0.0001 | 0.4382 |
| | Subject | P Value | 0.4785 | < 0.0001 | 0.0841 | 0.4462 |
| Outlier Deleted | Practice | Percentage Contribution | 0,5429 | 0,5596 | 0,6422 | 0,1518 |
| | | P Value | 0.0013 | 0.0009 | < 0.0001 | 0.5223 |
| | Subject | P Value | 0.1084 | < 0.0001 | 0.0159 | 0.3682 |
| Regression applied for outlier | Practice | Percentage Contribution | 0.5513 | 0.5632 | 0.6496 | 0.1345 |
| | | P Value | 0.0008 | 0.0006 | < 0.0001 | 0.5755 |
| | Subject | P Value | 0.0759 | < 0.0001 | 0.0122 | 0.1242 |

There are two alterations for outlier: deleting outlier or using regression for outlier. The two cases will be applied to existing data and analyses are redone. For the following analysis, subject 44's second trial is assumed to be an outlier. In the first analysis, it is deleted and analysis is done with the remaining 35 data points. Table 6.13 shows the P-values for practice and subject effects together with percentage variation explained with practice effect. In the second analysis for the outlier, score is estimated with results obtained by subject's previous and subsequent run. When the obtained result for regression compared with deleting, it is seen that similar results are obtained (See Table 6.13). In these three analyses, for ±2 settling time performance measure, subject 44's 3rd trial remained as an outlier when his 2nd trial is deleted; his performance was so good that it fall outside the regular region. Since violation is not serious, the outlier will remain in the analysis.

Table 6.14. Pair-wise comparison of trials in both-delays: *dev-10-mt*

| | Treatment | 1vs2 | 1vs3 | 1vs4 | 1vs5 | 1vs6 | 2vs3 | 2vs4 | 2vs5 | 2vs6 | 3vs4 | 3vs5 | 3vs6 | 4vs5 | 4vs6 | 5vs6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prob > \|t\| | Original Data | 0.15 | 0.32 | 0.18 | 0.03 | 0 | 0.02 | 0.01 | 0 | 0 | 0.71 | 0.2 | 0.04 | 0.35 | 0.09 | 0.43 |
| | Outlier Deleted | 0.69 | 0.2 | 0.08 | 0.01 | 0 | 0.11 | 0.04 | 0 | 0 | 0.63 | 0.1 | 0.01 | 0.23 | 0.03 | 0.31 |
| | Regression Applied for Outlier | 0.73 | 0.19 | 0.08 | 0 | 0 | 0.1 | 0.04 | 0 | 0 | 0.62 | 0.09 | 0.01 | 0.22 | 0.03 | 0.3 |

Table 6.14 shows whether differences between two trials are significant or not. With original data, it can only be concluded that trial 1 and trial 2 are statistically different than trial 5 and trial 6. The reason for this low level of differentiation is the variance which is 47.73. More differentiation could be carried out for the other two analyses where outlier is deleted or regression applied for outlier.

Table 6.15. Mean scores obtained in both-delays game: *dev-10-mt*

| | Trial # | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|---|---|---|---|---|---|---|---|
| Estimated Mean | Original Data | 316 | 399 | 259 | 238 | 185 | 140 |
| | Outlier Deleted | 316 | 334 | 259 | 238 | 185 | 140 |
| | Regression Applied for Outlier | 316 | 331 | 259 | 238 | 185 | 140 |

In this analysis, trials 1 and 2 are found significantly worse than trials 4, 5 and 6, whereas trial 3 is found significantly worse than trial 5 and 6 (See Table 6.15). We can conclude that trial 1 and 2 are the worst trials. At trial 3, an improvement is observed and the improvement trend is continued up to trial 6. However, differences between two consecutive trials are not significant such as 3 and 4, 4 and 5, 5 and 6. When scores compared with two further trials, significant differences are observed such as 3 and 5, 4 and 6. These results are for *dev-10-mt* performance measure, but can be extended to other performance measures where similar differences between trials are observed.

### 6.1.5. Games with Pause Option

The time pressure acting during decision process is potentially effective on the performance of the subjects. However, in the Latin Square experimental design, game speed is found ineffective for some performance measures. The reason for ineffectiveness of game speed on performance may be that the game speeds used in experiments are not different enough to see the effect. Thus, a game with "pause" option is designed. In this game, subjects may "pause" the game and continue whenever they want. In other words, they have plentiful time to think and decide.

Figure 6.10 shows two output behaviors obtained in both delays game with pause option by two different subjects. In both games, oscillations are observed. However, the game in the left part of the graph shows larger deviations from desired depth. Subject 50, in this first trial, oscillates between surface and desired depth. Subject 52, in the fifth trial, maintains a better control compared to Subject 50. Although oscillations are also observed, amplitudes are significantly smaller. The output behaviors obtained in both-delays games with pause option by Subject 47-53 can be seen in Appendix F.

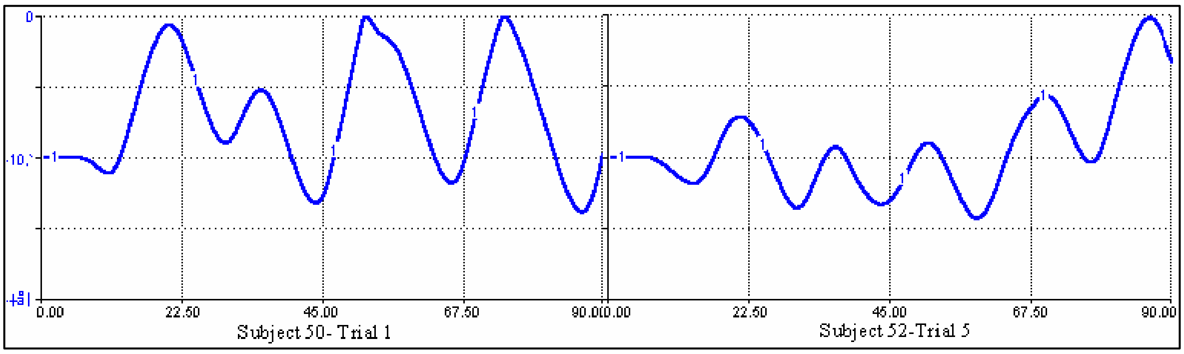



Figure 6.10. Typical results obtained in both-delays game with pause option

Figure 6.11 shows the performances obtained by seven subjects in their six trials in games with pause option. Subjects can be divided into two groups depending on their performances in the game. Subjects 48 and 52 performed worse than average whereas

Subjects 47, 49, 50 51 and 53 were better than average. The maximum and minimum scores obtained by first group varies largely whereas difference between maximum and minimum scores obtained in the second group is barely higher than 200.

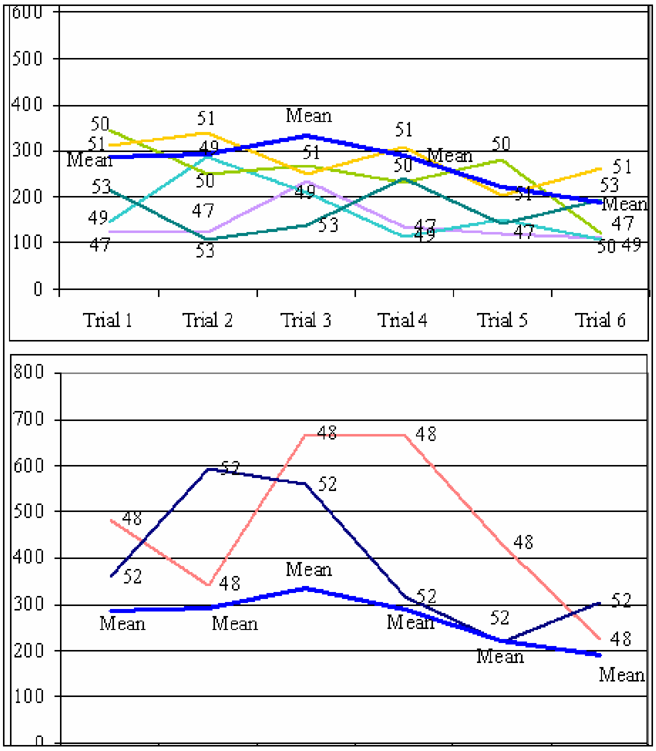



Figure 6.11. Scores obtained in both-delays game with pause option by subjects 47-53: *dev-10-mt*

The pause option is presented to subjects as a tool which would be helpful in their games. They are encouraged to use pause option. Subject 47 used pause option only once and only in trial 2. He stated that he did not need to use pause, because his strategy would not change with additional time to think. He also affirmed that with pause option, he lost attention. On the other hand, after first trial subject 48 said that she could not decide when to use pause option. After second trial, she concluded that pause option is not necessary and she did not use pause option in any of the trials. Like subject 48, subject 49, 50, 51, 52 and 53 stated that they did not need to use pause option and did not use it in any of the 6 trials. To conclude, none of the subjects felt using “pause” button necessary and helpful.

Next, statistical analysis carried out. Practice effect and significance of differences between subjects are investigated. Before discussing results, it has to be mentioned that for

*Caisson-RI* subject 48's second trial and for *±2 settling time* subject 49's trial 5 are found to be outliers. In Table 6.16, the results found in analysis of variance are summarized. Since violation is not severe, it is concluded that there is not a significant violation of assumptions.

As seen in Table 6.16 and Appendix E, subjects' performances are differed from each other for most of the performance measures. Thus, blocking should be used for each subject instead of replications. On the other hand, it is seen that performance at least in one trial is different from others for half of the performance measures.

Table 6.16. Percentage contribution and P values of subject and practice effect in both-delays game played with pause option for primary performance measures

| Source of Variation | | Deviation Area from 10 meters | Total Amplitude of Fluctuations | Maximum Deviation from 10 meters | ±2 Settling Time |
|---|---|---|---|---|---|
| Practice | Percentage Contribution | 0,2750 | 0,2140 | 0,3016 | 0,2487 |
| | P Value | 0.0722 | 0.1816 | 0.046 | 0.1096 |
| Subject | P Value | < 0.0001 | < 0.0001 | 0.003 | 0.0527 |

In the analysis, it is found that there are differences between trials. Next, differences between each consecutive trial are tested. Table 6.18 and Table 6.17 are obtained for *dev-10-mt* performance measure. As the mean values obtained at each trial are analyzed, it is seen that performance in trial 3 is worse than all other trials. The reason for this high mean score can be attributed to low performances of subjects 48 and 52 in these trials.

Table 6.17. Mean scores obtained in both-delays game with pause option: *dev-10-mt*

| Trial # | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|---|---|---|---|---|---|---|
| Estimated Mean | 285 | 292 | 333 | 288 | 221 | 189 |

Performance in trial 5 and 6 is found to be significantly better than other trials, but no significant difference between first four trials is detected. Thus, in the first four trials there is not a significant improvement in performance. At fifth trial, an improvement observed and this level of success is preserved in the last trial.

Table 6.18. Pair-wise comparison of trials in both-delays game with pause option: *dev-10-mt*

| Treatment | 1vs2 | 1vs3 | 1vs4 | 1vs5 | 1vs6 | 2vs3 | 2vs4 | 2vs5 | 2vs6 | 3vs4 | 3vs5 | 3vs6 | 4vs5 | 4vs6 | 5vs6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prob > \|t\| | 0.88 | 0.34 | 0.95 | 0.21 | 0.06 | 0.41 | 0.93 | 0.16 | 0.05 | 0.37 | 0.03 | 0.01 | 0.19 | 0.06 | 0.52 |

### 6.1.6. Scuba Divers

Since scuba diving process is modeled in a dynamic decision making environment, it is worthwhile to investigate performances of professional scuba divers. In this part, performances of six scuba divers in no delay game will be visually and statistically analyzed. The significance of scuba diving experience and practice effects will be questioned. In the following sections, results will be compared with non scuba divers to see whether there are differences between scuba divers and non scuba divers. Since scuba divers have real diving experience, it is expected that they will be more successful than non scuba divers.

Two typical results obtained in no delay games by scuba divers can be seen in Figure 6.12. While almost constant amplitude oscillations is observed in the first trial of Subject 59, Subject 55 in the fifth trial performs satisfactorily and achieves continuous stability around desired depth. The performance differences might be dependent on subjects and practice effect. Graphical game results obtained in no delay game by scuba divers, Subject 54-59, can be seen in Appendix F.

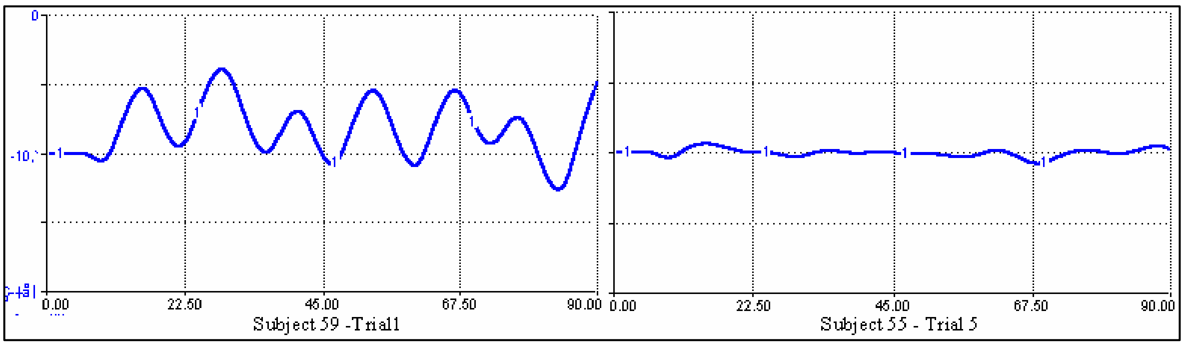



Figure 6.12. Typical results obtained in no delay games by scuba divers

Firstly, visual analysis will be carried out to get an initial idea of performances of divers. Unfortunately, due to a problem, subject 58's 6th trial is missing. Subjects are divided into two groups with respect to their performances. In the first group, subject 54, 55, 56 and 57 performed satisfactorily and preserved or improved their performances. In the second group, subject 58 and 59 are not successful in the first trials. Subject 59 has similar scores throughout trials. Subject 58 experienced two step improvements. Since we don't know his last trial, it is not safe to make comment on his performance pattern.

In the first experimental design, where each subject is taken as a separate factor, it is found that there are significant differences between subjects. Thus, in the second experimental design, each subjects' data is not used as a replication but a separate block. When the normality assumption of residuals is checked, it is observed that Subject 58's second trial is an outlier. As the output behavior is investigated, enough evidence is not found. Thus, this data point is included in the analysis without any adjustment. The P-values and percentage of variation that can be explained by practice effect can be seen in Table 6.19.

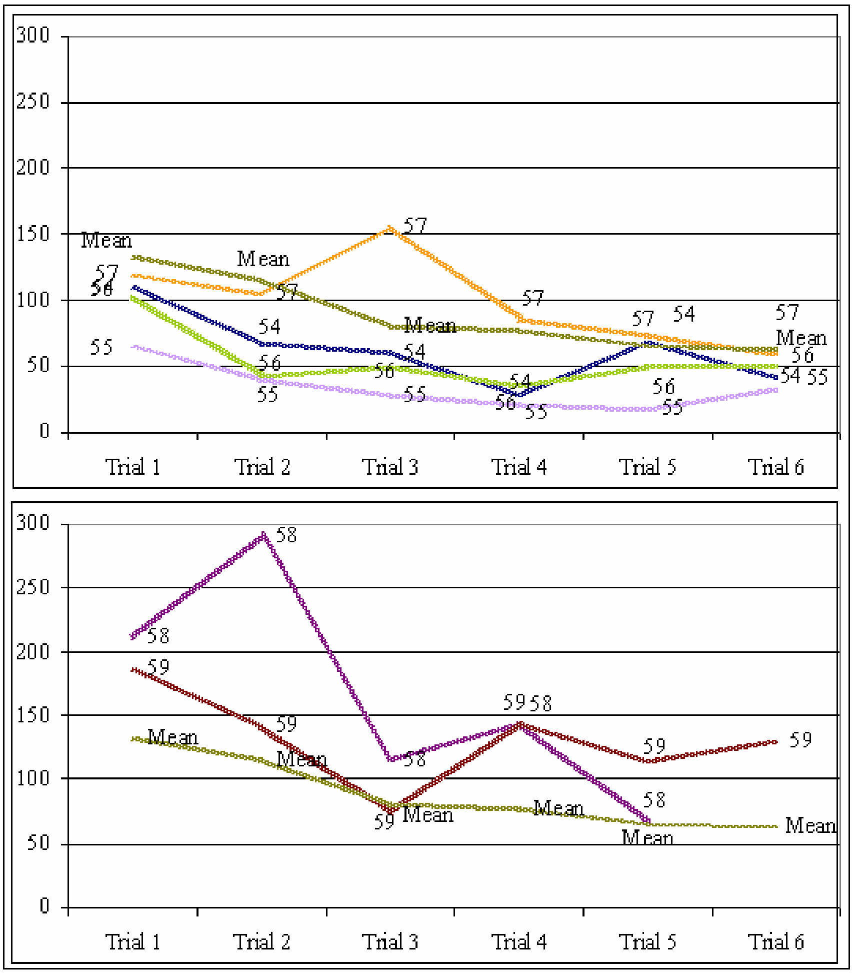



Figure 6.13. Scores obtained in no delay game by scuba divers (subjects 54-59): *dev-10-mt*

Table 6.19. Percentage contribution and P values of subject and practice effect in no delay game played by scuba divers for primary measures

| Source of Variation | | Deviation Area from 10 meters | Total Amplitude of Fluctuations | Maximum Deviation from 10 meters | ±2 Settling Time |
|---|---|---|---|---|---|
| Practice | Percentage Contribution | 0.4 | 0.53 | 0.18 | 0.27 |
| | P Value | 0.03 | 0 | 0.43 | 0.16 |
| Subject | P Value | < 0.0001 | < 0.0001 | 0 | < .0001 |

For *dev-10-mt* performance measure, Table 6.20 and Table 6.21 show the mean values obtained at each trial and the significance of differences between trial means. With the original data, it is seen that performance in first trial is significantly different than other trials but trial 2. At the third trial, an improvement in performance is observed and this level of success is preserved in the remaining trials.

Table 6.20. Pair-wise comparison of trials in no delay game played by scuba divers: *dev-10-mt*

| Treatment | 1vs2 | 1vs3 | 1vs4 | 1vs5 | 1vs6 | 2vs3 | 2vs4 | 2vs5 | 2vs6 | 3vs4 | 3vs5 | 3vs6 | 4vs5 | 4vs6 | 5vs6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prob > \|t\| | 0.4 | 0.02 | 0.01 | 0 | 0.02 | 0.12 | 0.08 | 0.03 | 0.1 | 0.86 | 0.48 | 0.88 | 0.59 | 0.98 | 0.59 |

Table 6.21. Mean scores obtained in no delay game played by scuba divers: *dev-10-mt*

| Trial # | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|---|---|---|---|---|---|---|
| Estimated Mean | 133 | 115 | 81 | 77 | 66 | 77 |

## 6.2. Comparisons Between Games

Effects of information and material delays and their interaction, effect of game speed (time pressure) and diving experience will be analyzed in this section. The repeated measures analysis tool of SPSS statistical software is utilized for the analysis.

For repeated measures analysis, independence, multivariate normality (equality of variances between groups) assumptions, which are also standard assumptions for an ordinary analysis, should hold. Although the violation of independence assumption is very serious, violation of multivariate normality is not so severe. Since subjects are randomly selected and assigned to each group, independence assumption holds for the analysis.

Multivariate normality can be tested with Box's M Test. Unfortunately, for some performance measures and game comparisons Box's M value can not be calculated. Additionally, this test is very sensitive to deviations from normality. Thus, Levene'e Test of equality of variances is recommended. The results of both tests are presented in the Appendix E for each comparison. Even if there is a significant violation of multivariate normality, no additional action is taken since ANOVA is robust against deviations from normality.

For repeated measures analysis, sphericity assumption should also hold for univariate approach. If sphericity assumption does not hold, either multivariate approach should be used or degrees of freedom values should be adjusted. However, in our design sample size is not large enough to use multivariate approach. Thus, in violation of sphericity assumption, adjustment in degrees of freedom values option is chosen. Sphericity assumption is tested with transformed variables where transformation matrix is orthogonal. Sphericity assumption holds if transformed variables are uncorrelated where variances are equal. Sphericity assumption will be tested with Maucly's test of sphericity. For the performance measures that sphericity assumption does not hold, degrees of freedom values have to be multiplied with the given coefficients; Greenhouse-Geisser, Huynh-Feldt or Lower-bound. In this section, a compact form of ANOVA table will be presented, however the reader is referred to Appendix E for complete ANOVA tables which include results for all adjustment coefficients; Greenhouse-Geisser, Huynh-Feldt and Lower-bound. (Stevens, 1996)

In ANOVA tables, partial eta squared values are also presented. Partial eta squared value is the ratio between variation due to a model parameter and sum of variation due to the model parameter and error.

### 6.2.1. No Delay - Material Delay Comparison

Diehl and Sterman in their study showed that human beings usually misperceive feedbacks; they usually ignore supply lines (previously given but not received orders) which is a consequence of delays (Diehl and Sterman, 1995). This misperception results in oscillatory behaviors which also bring high cost and other burdens to decision maker. One type of ScubaSim game is designed only to account for the effects of material delay on the performance of subjects. To analyze the material delay structure, the reader is referred to the Interactive Simulation Game (ScubaSim) chapter of the thesis.

Table 6.22. Scores in no delay and material delay: *dev-10-mt* and *amp-of-fluct*

| | | Deviation Area from 10 meters | | | | | | Total Amplitude of Fluctuations | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No delay | Subject 17 | 86 | 76 | 69 | 83 | 126 | 82 | 39 | 36 | 13 | 23 | 14 | 21 |
| | Subject 18 | 238 | 195 | 131 | 84 | 150 | 69 | 65 | 65 | 53 | 38 | 49 | 40 |
| | Subject 19 | 72 | 88 | 61 | 72 | 59 | 68 | 33 | 17 | 18 | 30 | 21 | 30 |
| | Subject 20 | 216 | 137 | 40 | 50 | 37 | 52 | 43 | 31 | 16 | 19 | 18 | 18 |
| | Subject 21 | 204 | 121 | 71 | 140 | 93 | 179 | 58 | 47 | 39 | 53 | 34 | 22 |
| | Subject 22 | 84 | 89 | 47 | 56 | 33 | 67 | 33 | 25 | 17 | 22 | 13 | 19 |
| | Subject 23 | 296 | 255 | 99 | 88 | 77 | 56 | 83 | 69 | 33 | 30 | 29 | 14 |
| | Subject 24 | 44 | 73 | 52 | 71 | 78 | 55 | 16 | 13 | 10 | 15 | 22 | 17 |
| Material | Subject 25 | 383 | 243 | 186 | 214 | 317 | 120 | 65 | 58 | 39 | 40 | 50 | 28 |
| | Subject 26 | 93 | 81 | 127 | 97 | 78 | 75 | 36 | 29 | 36 | 30 | 25 | 21 |
| | Subject 27 | 209 | 74 | 164 | 179 | 76 | 130 | 63 | 28 | 51 | 39 | 19 | 26 |
| | Subject 28 | 258 | 162 | 240 | 188 | 167 | 168 | 72 | 53 | 51 | 61 | 63 | 52 |
| | Subject 29 | 195 | 181 | 200 | 85 | 72 | 104 | 61 | 41 | 41 | 19 | 19 | 24 |
| | Subject 30 | 179 | 252 | 288 | 198 | 123 | 188 | 55 | 59 | 63 | 60 | 40 | 55 |
| | Subject 31 | 141 | 239 | 205 | 286 | 105 | 118 | 59 | 64 | 64 | 76 | 41 | 47 |
| | Subject 32 | 154 | 259 | 168 | 132 | 129 | 99 | 55 | 68 | 39 | 49 | 34 | 38 |

Firstly, graphical and numerical inspection will be conducted. Figure 6.14 shows the scores obtained in no delay and material delay games with *dev-10-mt* whereas Table 6.22 shows scores obtained in no delay and material delay games with respect to *dev-10-mt* and *amp-of-fluct* performance measures.

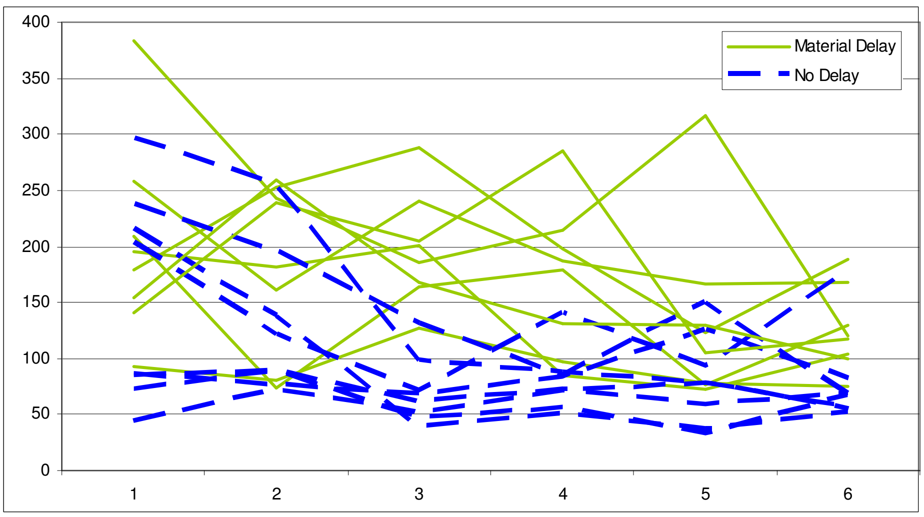



Figure 6.14. Scores in material delay and no delay games: *dev-10-mt*

In the first two trials, differences between scores obtained in material and no delay game are not significant (See Figure 6.14). In the third trial, subjects who played no delay game made a significant improvement but the same improvement can not be observed in material delay group. Thus, significant difference is seen between the two groups in trial 3 and 4. In material delay group, significant improvements and deteriorations are seen in the consecutive trials. In no delay games, erroneous decisions can be compensated easily but in delay condition these errors would result in high scores. Thus, a high variation is observed in material delay group between trials and between subjects.

Before going into statistical analysis, statistical model assumptions have to be checked. The results of Box's M test and Levene's test of equality of error variances can be seen in Appendix E. Levene's test results show that the assumption holds for all trials and performance measures but ±2 settling time. Subjects are able to settle down when there is no delay, but in the existence of a delay, information or material, subjects usually are unable to settle down. Thus, score obtained in games with delay are usually full simulation length (90) and variance is low. On the other hand, in games without delay subjects may or may not settle down which results in high variation. For this reason, equality of error variances between groups assumption does not hold for ±2 settling time performance measure. But, since the violation of this assumption is not serious, analysis will be done with original data.

When the sphericity assumption is checked with Mauchly's test of sphericity, it is found that assumption holds for all performance measures but Caisson-RI. For this performance measure, degrees of freedom values will be adjusted with given epsilon values (See Appendix E).

After validating model assumptions, we continue with statistical analysis. We will discuss primary performance measures in this section whereas results of secondary performance measures can be seen in the Appendix E.

Material delay is found to be significant for all performance measures except *dev-mean-10mt* performance measure (See Table 6.23). Thus, existence of delays deteriorates the performance of subjects significantly. Continuing with within-subject variation, it is found that practice effect is significant. To analyze the practice effect, scores obtained in *dev-10-mt* performance measure is used. When mean differences are analyzed, it is observed that mean differences are always positive, which means that performance continuously improved throughout the trials (See Table 6.24). Trial 1 is found to be significantly different than all trials but trial 2. Trial 2 is found to be significantly worse than all trials but trial 3. The mean score obtained in trial 3 is not different than scores in trial 4 and 5 but worse than trial 6. It is not possible for trials to divide into separate groups but it is observed that there is a continuous improvement over trials.

Table 6.23. ANOVA Table for practice and material delay effects: primary measures

| | Dev-10-mt | | Amp-of-fluct | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|
| Source | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | |
| practice | 0 | 0.28 | 0 | 0.46 | 0 | 0.28 | 0 | 0.25 |
| practice * Material Delay | 0.15 | 0.11 | 0.5 | 0.06 | 0.5 | 0.06 | 0.02 | 0.17 |
| Tests of Between-Subjects Effects | | | | | | | | |
| Intercept | 0 | 0.92 | 0 | 0.92 | 0 | 0.91 | 0 | 0.96 |
| Material Delay | 0.01 | 0.44 | 0.03 | 0.31 | 0.02 | 0.34 | 0 | 0.52 |

Table 6.24. Pair-wise comparison of trials in no delay-material delay games: *dev-10-mt*

| Trial | Trial | Mean Difference | Std. Error | Significance |
|---|---|---|---|---|
| 1 | 2 | 20,39 | 19,37 | 0,31 |
| | 3 | 44,05 | 21,43 | 0,06 |
| | 4 | 51,85 | 22,89 | 0,04 |
| | 5 | 70,7 | 18,41 | 0 |
| | 6 | 76,32 | 22,83 | 0 |
| 2 | 3 | 23,66 | 14,37 | 0,12 |
| | 4 | 31,47 | 17,98 | 0,1 |
| | 5 | 50,31 | 18,83 | 0,02 |
| | 6 | 55,93 | 19,55 | 0,01 |
| 3 | 4 | 7,81 | 12,67 | 0,55 |
| | 5 | 26,65 | 16,34 | 0,13 |
| | 6 | 32,27 | 9,69 | 0 |
| 4 | 5 | 18,84 | 16,06 | 0,26 |
| | 6 | 24,46 | 11,05 | 0,04 |
| 5 | 6 | 5,62 | 17,16 | 0,75 |

As observed in within-subjects variation analysis, practice effect is significant but (practice) x (material delay) effect is not significant. In material delay group, there is not a significant improvement in the first three trials. However, an increasing trend in performance is seen at the remaining three trials. On the other hand, in no delay games, significant improvement in the first three trials is observed whereas for the remaining trials no further improvement is observed which is exactly opposite of material delay case. Although, visual analysis shows that improvement patterns are different for no delay and material delay games, we have not enough evidence to conclude that they are statistically different.

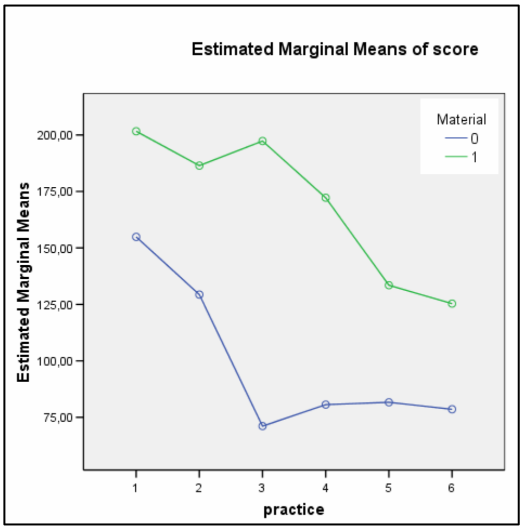



Figure 6.15. Mean scores in each trial with and without material delay: *dev-10-mt*

### 6.2.2. No Delay - Information Delay Comparison

In literature, material delays are widely studied whereas information delay has taken little attention. However, both of the delay structures may have significant effects on performance. For this reason, information delay is added to ScubaSim to account the effect of the delay. The information delay structure can be investigated from Interactive Simulation Game (ScubaSim) chapter of the thesis. Subjects will observe their depth after some delay. Since they also perceive their velocity from depth trajectory, there is an implicit information delay in velocity perception.

Table 6.25 shows *dev-10-mt* and *amp-of-fluct* scores and Figure 6.16 shows only the *dev-10-mt* scores obtained by the subjects who played in information delay and no delay games. When the distribution of scores over trials and over game type is analyzed, the most striking characteristic is that the variation. The variation of scores in information delay games is very high. Since the game is played in real time, this variation may be seen reasonable.

Table 6.25. Scores in no delay-information delay games: *dev-10-mt* and *amp-of-fluct*

| | | Deviation Area from 10 meters | | | | | | Total Amplitude of Fluctuations | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No delay | Subject 17 | 86 | 76 | 69 | 83 | 126 | 82 | 39 | 36 | 13 | 23 | 14 | 21 |
| | Subject 18 | 238 | 195 | 131 | 84 | 150 | 69 | 65 | 65 | 53 | 38 | 49 | 40 |
| | Subject 19 | 72 | 88 | 61 | 72 | 59 | 68 | 33 | 17 | 18 | 30 | 21 | 30 |
| | Subject 20 | 216 | 137 | 40 | 50 | 37 | 52 | 43 | 31 | 16 | 19 | 18 | 18 |
| | Subject 21 | 204 | 121 | 71 | 140 | 93 | 179 | 58 | 47 | 39 | 53 | 34 | 22 |
| | Subject 22 | 84 | 89 | 47 | 56 | 33 | 67 | 33 | 25 | 17 | 22 | 13 | 19 |
| | Subject 23 | 296 | 255 | 99 | 88 | 77 | 56 | 83 | 69 | 33 | 30 | 29 | 14 |
| | Subject 24 | 44 | 73 | 52 | 71 | 78 | 55 | 16 | 13 | 10 | 15 | 22 | 17 |
| Information Delay | Subject 33 | 301 | 246 | 227 | 115 | 323 | 203 | 39 | 44 | 31 | 17 | 45 | 21 |
| | Subject 34 | 342 | 300 | 153 | 198 | 96 | 134 | 83 | 66 | 49 | 52 | 34 | 48 |
| | Subject 35 | 302 | 220 | 108 | 207 | 142 | 96 | 79 | 55 | 34 | 49 | 51 | 32 |
| | Subject 36 | 497 | 106 | 127 | 184 | 74 | 118 | 81 | 33 | 39 | 44 | 18 | 32 |
| | Subject 37 | 438 | 170 | 323 | 217 | 138 | 191 | 81 | 61 | 66 | 46 | 34 | 35 |
| | Subject 38 | 282 | 118 | 170 | 138 | 95 | 50 | 73 | 41 | 49 | 47 | 30 | 21 |
| | Subject 39 | 180 | 154 | 242 | 155 | 372 | 284 | 52 | 42 | 48 | 48 | 64 | 76 |
| | Subject 40 | 245 | 321 | 134 | 101 | 84 | 108 | 44 | 62 | 26 | 23 | 21 | 26 |

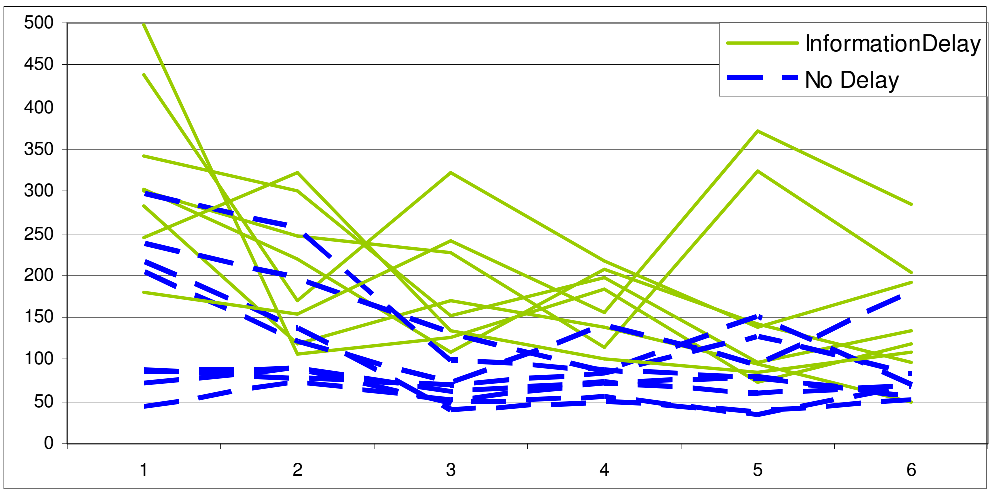



Figure 6.16. Scores in information delay and no delay games: *dev-10-mt*

Subjects played in no delay game, performed better than subjects played in information delay game (See Figure 6.16). In no delay games, performance improved or deteriorated mildly between consecutive trails. On the other hand, variation of performance in information delay games is very high; there are large improvements and large deteriorations between consecutive trials.

After the third trial, subjects in no delay group performed very similar to each other. The variation of scores obtained in the last four trials is very low. For information delay games, differences between subjects remained significant.

Before statistical analysis, equality of variances and sphericity assumptions have to be checked. Equality of variances assumption holds for all performance measure but ± 2 settling time (See Appendix E). The values in information delay are mostly 90, which mean that subjects can not able to settle down. On the other hand, in no delay condition, settling times are various and variance is high. The equality of error variances assumption does not hold due to this reason.

Next, sphericity assumption is checked with Mauchly's test of sphericity. Sphericity assumption does not hold for most of the performance measures. For these performance measures, degrees of freedom values are multiplied with the epsilon values given.

Table 6.26. ANOVA Table for practice and information delay effects: primary measures

| | Dev-10-mt | | Amp-of-fluct | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|
| Source | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | |
| Practice | 0 | 0.37 | 0 | 0.47 | 0 | 0.33 | 0 | 0.26 |
| Practice * Information Delay | 0.3 | 0.08 | 0.87 | 0.03 | 0.8 | 0.03 | 0.03 | 0.16 |
| Tests of Between-Subjects Effects | | | | | | | | |
| Intercept | 0 | 0.95 | 0 | 0.93 | 0 | 0.91 | 0 | 0.97 |
| Information Delay | 0 | 0.68 | 0.02 | 0.33 | 0 | 0.46 | 0 | 0.54 |

After validating that assumptions hold, statistical tests are used to investigate the effect of information delay on subjects' performances. When between-subjects variation is analyzed, information effect is found to be significant for all performance measures. Thus, it can be concluded that subject's performance is significantly affected by the existence of information delay. When the estimated scores for *dev-10-mt* performance measure is investigated, it is seen that mean score in information delay condition is 198 whereas the score in no delay condition is 99.

Table 6.27. Pair-wise comparison of trials in no delay-information delay games: *dev-10-mt*

| Trial | Trial | Mean Difference | Std. Error | Significance |
|---|---|---|---|---|
| 1 | 2 | 72,26 | 27,46 | 0,02 |
| | 3 | 110,82 | 25,88 | 0 |
| | 4 | 116,64 | 21,83 | 0 |
| | 5 | 115,56 | 37,58 | 0,01 |
| | 6 | 125,82 | 30,24 | 0 |
| 2 | 3 | 38,56 | 22,88 | 0,11 |
| | 4 | 44,38 | 21,42 | 0,06 |
| | 5 | 43,3 | 28,4 | 0,15 |
| | 6 | 53,56 | 24,41 | 0,05 |
| 3 | 4 | 5,83 | 15,26 | 0,71 |
| | 5 | 4,74 | 18,55 | 0,8 |
| | 6 | 15 | 13,66 | 0,29 |
| 4 | 5 | -1,09 | 24,57 | 0,97 |
| | 6 | 9,18 | 15,63 | 0,57 |
| 5 | 6 | 10,26 | 14,77 | 0,5 |

Continuing with within-subjects variation, practice effect is statistically significant but (practice) x (information delay) interaction effect is not statistically significant. Subjects' performances changed between trials but this change is independent of existence of information delay. Next, change in performance between two consecutive trials is investigated. In Table 6.27, differences between estimated mean values of two trials and their significance can be seen. Performance in trial 1 is significantly different than other trials. Trial 2 is found to be worse than the subsequent trials. However, trial 3, 4, 5 and 6 are not statistically different from each other. To sum up, performance in the first two trials remained the same, there observed an improvement in trial 3 and performance stayed in the same level in the following trials.

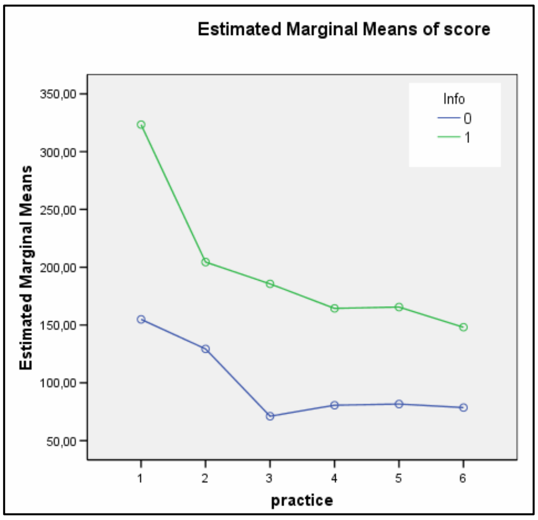



Figure 6.17. Mean scores in no delay and information delay games: *dev-10-mt*

As the scores obtained in no delay and information delay games are analyzed visually, it is seen that general trend in two games are similar. In other words, the two trajectories remain parallel to each other which also show that there is not a significant interaction effect.

### 6.2.3. No Delay- Material Delay- Information Delay Comparison

In his studies Brehmer examined the differences between dead time delay and information delay (Brehmer, 1995). He found that subjects in information delay group performed better than dead time group but worse than no delay group. Additionally, it is also observed that subjects' performances in information delay games became as good as no delay group after three trials.

Table 6.28. Scores in no delay, material delay and information delay games: *dev-10-mt* and *amp-of-fluct*

| | | Deviation Area from 10 meters | | | | | | Total Amplitude of Fluctuations | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No delay | Subject 17 | 86 | 76 | 69 | 83 | 126 | 82 | 39 | 36 | 13 | 23 | 14 | 21 |
| | Subject 18 | 238 | 195 | 131 | 84 | 150 | 69 | 65 | 65 | 53 | 38 | 49 | 40 |
| | Subject 19 | 72 | 88 | 61 | 72 | 59 | 68 | 33 | 17 | 18 | 30 | 21 | 30 |
| | Subject 20 | 216 | 137 | 40 | 50 | 37 | 52 | 43 | 31 | 16 | 19 | 18 | 18 |
| | Subject 21 | 204 | 121 | 71 | 140 | 93 | 179 | 58 | 47 | 39 | 53 | 34 | 22 |
| | Subject 22 | 84 | 89 | 47 | 56 | 33 | 67 | 33 | 25 | 17 | 22 | 13 | 19 |
| | Subject 23 | 296 | 255 | 99 | 88 | 77 | 56 | 83 | 69 | 33 | 30 | 29 | 14 |
| | Subject 24 | 44 | 73 | 52 | 71 | 78 | 55 | 16 | 13 | 10 | 15 | 22 | 17 |
| Material Delay | Subject 25 | 383 | 243 | 186 | 214 | 317 | 120 | 65 | 58 | 39 | 40 | 50 | 28 |
| | Subject 26 | 93 | 81 | 127 | 97 | 78 | 75 | 36 | 29 | 36 | 30 | 25 | 21 |
| | Subject 27 | 209 | 74 | 164 | 179 | 76 | 130 | 63 | 28 | 51 | 39 | 19 | 26 |
| | Subject 28 | 258 | 162 | 240 | 188 | 167 | 168 | 72 | 53 | 51 | 61 | 63 | 52 |
| | Subject 29 | 195 | 181 | 200 | 85 | 72 | 104 | 61 | 41 | 41 | 19 | 19 | 24 |
| | Subject 30 | 179 | 252 | 288 | 198 | 123 | 188 | 55 | 59 | 63 | 60 | 40 | 55 |
| | Subject 31 | 141 | 239 | 205 | 286 | 105 | 118 | 59 | 64 | 64 | 76 | 41 | 47 |
| | Subject 32 | 154 | 259 | 168 | 132 | 129 | 99 | 55 | 68 | 39 | 49 | 34 | 38 |
| Information Delay | Subject 33 | 301 | 246 | 227 | 115 | 323 | 203 | 39 | 44 | 31 | 17 | 45 | 21 |
| | Subject 34 | 342 | 300 | 153 | 198 | 96 | 134 | 83 | 66 | 49 | 52 | 34 | 48 |
| | Subject 35 | 302 | 220 | 108 | 207 | 142 | 96 | 79 | 55 | 34 | 49 | 51 | 32 |
| | Subject 36 | 497 | 106 | 127 | 184 | 74 | 118 | 81 | 33 | 39 | 44 | 18 | 32 |
| | Subject 37 | 438 | 170 | 323 | 217 | 138 | 191 | 81 | 61 | 66 | 46 | 34 | 35 |
| | Subject 38 | 282 | 118 | 170 | 138 | 95 | 50 | 73 | 41 | 49 | 47 | 30 | 21 |
| | Subject 39 | 180 | 154 | 242 | 155 | 372 | 284 | 52 | 42 | 48 | 48 | 64 | 76 |
| | Subject 40 | 245 | 321 | 134 | 101 | 84 | 108 | 44 | 62 | 26 | 23 | 21 | 26 |

In ScubaSim, the effects of information delay and material delay on subjects' performances are investigated. Although Yasarcan proved that information delay and material delay structures are the same, perception and handling of these delays may be different (Yasarcan, 2003). Even if delay structures are the same, they lie on the different levels of model and different feedbacks are given to subjects. Thus, any differences observed between delay types may be due to type of delay, feedback given to subjects and effect of delay on the model. Additionally, existence information delay in depth data implicitly produces information delay in velocity data with the same length of delay.

To test differences between delay types, subjects' performance data in no delay, material delay and information delay are utilized. Practice, delay type effects and (practice) x (delay type) interaction effect are tested. Table 6.28 shows the scores obtained by subjects with respect to *dev-10-mt* and *amp-of-fluct* performance measures. Graphical representation of *dev-10-mt* scores can be seen in Figure 6.14 and Figure 6.16.

Table 6.29. ANOVA Table for practice and delay type effects for primary measures

| | Dev-10-mt | | Amp-of-fluct | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|
| Source | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | |
| practice | 0,00 | 0,31 | 0,00 | 0,45 | 0,00 | 0,30 | 0,00 | 0,21 |
| practice * Delay Type | 0,12 | 0,13 | 0,76 | 0,06 | 0,83 | 0,05 | 0,01 | 0,19 |
| Tests of Between-Subjects Effects | | | | | | | | |
| Intercept | 0,00 | 0,94 | 0,00 | 0,94 | 0,00 | 0,93 | 0,00 | 0,98 |
| Delay Type | 0,00 | 0,55 | 0,02 | 0,31 | 0,00 | 0,41 | 0,00 | 0,58 |

Results of Box's M homogeneity of variances/covariances and Levene's Test of equality of error variances can be seen in Appendix E. It is seen that equality of error variances among groups assumption holds for most of the trials and performance measures, but violation of the assumption is observed in ±2 settling time. Continuing with sphericity assumption, it is observed that for most of the performance measures sphericity assumption does not hold thus epsilon values will be used in within subject variation analysis (See Appendix E). After statistical assumptions are validated, statistical results will be discussed. The results obtained for primary measures can be seen in Table 6.29 whereas the results for secondary measures can be found in the Appendix E. For all performance measures delay type and practice is found to be significant. However, their interaction effect is not significant for none of the performance measures.

The estimated mean scores and their confidence interval for *dev-10-mt* and *amp-of-fluct* performance measures can be seen in Table 6.30. Scores obtained in information delay and material delay games are significantly different than no delay game for *dev-10-mt* performance measure. Additionally, the difference between material delay and information delay is not significant, although subjects performed better in material delay games. Continuing with *amp-of-fluct* performance measure, material delay and information delay games are statistically different than no delay games, whereas scores obtained in material delay and information delay are not different from each other. Unlike, *dev-10-mt* performance measure, in *amp-of-fluct* a difference between material and informational delay can not be observed.

Table 6.30. Mean scores in no delay, information delay and material delay games: *dev-10-mt* and *amp-of-fluct*

| | Deviation Area from 10 meters | | | Total Amplitude of Fluctuations | | |
|---|---|---|---|---|---|---|
| Delay Type | Mean | 95% Confidence Int. | | Mean | 95% Confidence Int. | |
| Information | 198,58 | 173,9 | 223,26 | 45,72 | 38,88 | 52,55 |
| Material | 169,4 | 144,72 | 194,08 | 45,96 | 39,13 | 52,8 |
| No | 99,36 | 74,68 | 124,04 | 30,94 | 24,1 | 37,77 |

Table 6.31. Pair-wise comparison of scores in no delay and material delay and information delay games: *dev-10-mt*

| | | Dev-10-mt | | |
|---|---|---|---|---|
| Delay Type | Delay Type | Mean Difference | Std. Error | Significance |
| Info | Material | 29,18 | 2,028,535 | 0,17 |
| Info | No | 99,22 | 2,028,535 | 0,00 |
| Material | No | 70,04 | 2,028,535 | 0,00 |

As pair-wise comparisons are made between delay types, it is seen that scores obtained in information and material delay games are significantly worse than scores obtained in no delay games. Additionally, scores in information delay games are worse than scores obtained in material delay games but difference is not statistically significant. On average, subjects in material delay games have 70 points higher score than subjects in no delay games whereas the difference increases to 99 for information delay games. If we recall that the average score obtained in no delay games is 99, then these two differences become more meaningful which shows delays effect the performance of subjects.

As we try to differentiate the effect of material and information delay on performance, a relationship between performance deterioration and delay length is attempted to construct. The length of delays is equal to 0.5 in both games however in information delay games there is an additional information delay in velocity. Thus, delay length in material delay games remains as 0.5 seconds whereas in information delay games, it may be higher than 0.5 seconds. However, there is not a significant difference between information delay and material delay games. The relation between length of delay and performance will be investigated further in next section.

Table 6.32. Pair-wise comparison of trials in no delay and information and material delay games: *dev-10-mt*

| practice | practice | Mean Difference | Std. Error | Significance |
|---|---|---|---|---|
| 1 | 2 | 53,24 | 21,84 | 0,02 |
| | 3 | 75,31 | 20,34 | 0,00 |
| | 4 | 87,57 | 18,28 | 0,00 |
| | 5 | 99,75 | 25,58 | 0,00 |
| | 6 | 109,31 | 22,46 | 0,00 |
| 2 | 3 | 22,07 | 17,08 | 0,21 |
| | 4 | 34,33 | 16,93 | 0,06 |
| | 5 | 46,51 | 21,23 | 0,04 |
| | 6 | 56,07 | 18,48 | 0,01 |
| 3 | 4 | 12,26 | 12,67 | 0,34 |
| | 5 | 24,44 | 16,20 | 0,15 |
| | 6 | 34,00 | 9,48 | 0,00 |
| 4 | 5 | 12,18 | 19,09 | 0,53 |
| | 6 | 21,74 | 12,52 | 0,10 |
| 5 | 6 | 9,56 | 13,84 | 0,50 |

Previously, it is found that practice effect is significant for all performance measures. Next, patterns of performance change are investigated. Starting with pair-wise comparisons, it is seen that score obtained in trial 1 is worse than the remaining trials. In trial 2, a significant improvement in performance is observed. From that point, although there is improvement in successive trials, improvement is not statistically significant. For example, difference between trial 2 and trial 3 is not significant like the difference between trial 3 and trial 4. On the other hand, there are significant differences between non successive trials such as trial 2 is significantly worse than trial 4 and trial 3 is significantly worse than trial 6.

When within subjects variation is analyzed, it is seen that practice effect is statistically significant whereas (practice) x (delay type) interaction effect is found to be insignificant. The performance obtained in different delay types over the trials can be analyzed in Figure 6.18.

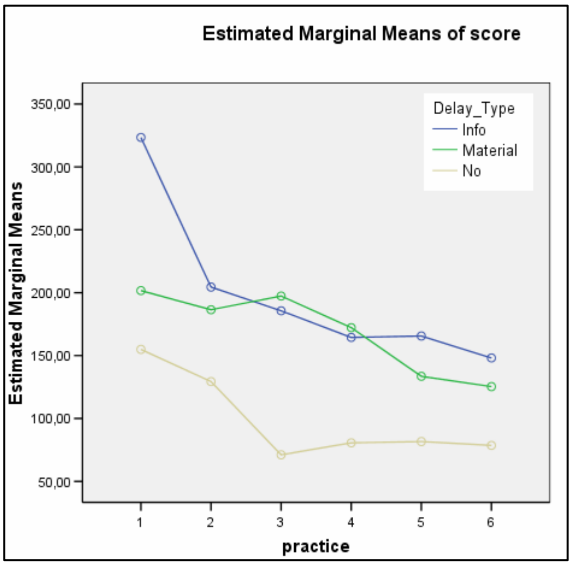



Figure 6.18. Mean scores obtained in games with respect to practice: *dev-10-mt*

In the first trial, the differences between groups are high where no delay group performed better than delay groups and information delay group performed the worst. A significant improvement is observed in games with information delay but performance remained similar in no delay and material delay groups. The improvement in information delay group can be attributed to the worse performance in the first trial. At trial 2, scores obtained in different type of games are very close to each other. After that point, delay games and no delay games are branched out. The performance in material and information delay games remained in the same levels with each other and mild performance improvement is observed, whereas in no delay game a step performance improvement is observed in third trial and performance, which is far better than performance obtained in delayed games, is protected over the remaining trials

To sum up, delay deteriorates the performance of subjects independent of its type, information or material. Subjects performed better in no delay games, whereas difference between material delay and information delay games is not significant. In both games, subjects are able to improve their performances but improvement pattern is not significantly dependent on the type of the delay. Thus, there is no statistically significant (practice) x (delay type) interaction effect.

### 6.2.4. No Delay- Both Delays Comparisons

In the previous sections, effects of material and information delays are inspected separately. However, there may be interaction effect between material and information delay, where in existence of both material delay and information delay, performance may be deteriorated much more then individual deteriorations due to material and information delay. Thus, in this section, effects of material and information delay and their interaction effect will be analyzed.

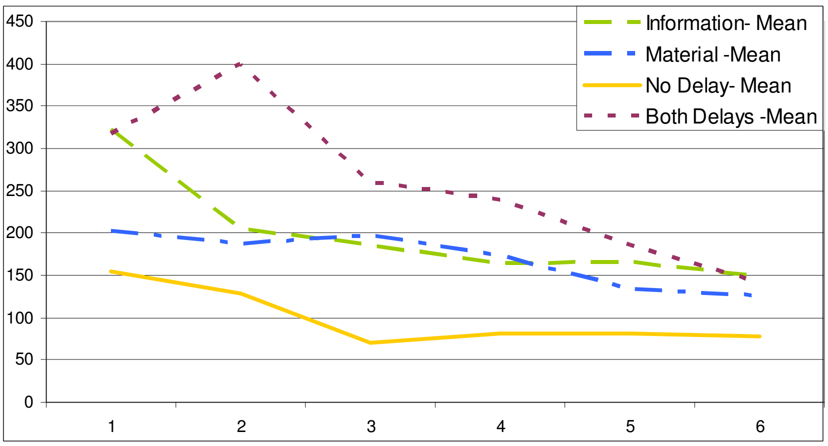



Figure 6.19: Mean scores obtained in games with respect to trials: *dev-10-mt*

Figure 6.19 shows the mean scores obtained in different games with respect to *dev-10-mt* performance measure. In the first trial, mean score obtained in information delay equals to mean score obtained in both delay. This situation can not be explained logically, but the reason may be the small sample size. At the 2nd, 3rd and 4th trials, an additive effect of delays is observed. In other words, mean scores obtained in both-delays games is not different than material delay effect (difference between material delay and no delay) and information delay effect (difference between information delay and no delay) added to no delay score (as a base score). This relation does not hold in the last two trials where there is not any significant difference between material delay, information delay and both-delays. This is an interesting finding which states that after enough practice, subjects performed as well as subjects played in material delay and information delay although they experienced both delays.

Table 6.33. Scores in no, material, information delay and both-delays game: *dev-10-mt* and *amp-of-fluct*

| | | Deviation Area from 10 meters | | | | | | Total Amplitude of Fluctuations | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No delay | Subject 17 | 86 | 76 | 69 | 83 | 126 | 82 | 39 | 36 | 13 | 23 | 14 | 21 |
| | Subject 18 | 238 | 195 | 131 | 84 | 150 | 69 | 65 | 65 | 53 | 38 | 49 | 40 |
| | Subject 19 | 72 | 88 | 61 | 72 | 59 | 68 | 33 | 17 | 18 | 30 | 21 | 30 |
| | Subject 20 | 216 | 137 | 40 | 50 | 37 | 52 | 43 | 31 | 16 | 19 | 18 | 18 |
| | Subject 21 | 204 | 121 | 71 | 140 | 93 | 179 | 58 | 47 | 39 | 53 | 34 | 22 |
| | Subject 22 | 84 | 89 | 47 | 56 | 33 | 67 | 33 | 25 | 17 | 22 | 13 | 19 |
| | Subject 23 | 296 | 255 | 99 | 88 | 77 | 56 | 83 | 69 | 33 | 30 | 29 | 14 |
| | Subject 24 | 44 | 73 | 52 | 71 | 78 | 55 | 16 | 13 | 10 | 15 | 22 | 17 |
| Material Delay | Subject 25 | 383 | 243 | 186 | 214 | 317 | 120 | 65 | 58 | 39 | 40 | 50 | 28 |
| | Subject 26 | 93 | 81 | 127 | 97 | 78 | 75 | 36 | 29 | 36 | 30 | 25 | 21 |
| | Subject 27 | 209 | 74 | 164 | 179 | 76 | 130 | 63 | 28 | 51 | 39 | 19 | 26 |
| | Subject 28 | 258 | 162 | 240 | 188 | 167 | 168 | 72 | 53 | 51 | 61 | 63 | 52 |
| | Subject 29 | 195 | 181 | 200 | 85 | 72 | 104 | 61 | 41 | 41 | 19 | 19 | 24 |
| | Subject 30 | 179 | 252 | 288 | 198 | 123 | 188 | 55 | 59 | 63 | 60 | 40 | 55 |
| | Subject 31 | 141 | 239 | 205 | 286 | 105 | 118 | 59 | 64 | 64 | 76 | 41 | 47 |
| | Subject 32 | 154 | 259 | 168 | 132 | 129 | 99 | 55 | 68 | 39 | 49 | 34 | 38 |
| Information Delay | Subject 33 | 301 | 246 | 227 | 115 | 323 | 203 | 39 | 44 | 31 | 17 | 45 | 21 |
| | Subject 34 | 342 | 300 | 153 | 198 | 96 | 134 | 83 | 66 | 49 | 52 | 34 | 48 |
| | Subject 35 | 302 | 220 | 108 | 207 | 142 | 96 | 79 | 55 | 34 | 49 | 51 | 32 |
| | Subject 36 | 497 | 106 | 127 | 184 | 74 | 118 | 81 | 33 | 39 | 44 | 18 | 32 |
| | Subject 37 | 438 | 170 | 323 | 217 | 138 | 191 | 81 | 61 | 66 | 46 | 34 | 35 |
| | Subject 38 | 282 | 118 | 170 | 138 | 95 | 50 | 73 | 41 | 49 | 47 | 30 | 21 |
| | Subject 39 | 180 | 154 | 242 | 155 | 372 | 284 | 52 | 42 | 48 | 48 | 64 | 76 |
| | Subject 40 | 245 | 321 | 134 | 101 | 84 | 108 | 44 | 62 | 26 | 23 | 21 | 26 |
| Both Delays | Subject 41 | 342 | 300 | 153 | 198 | 96 | 134 | 83 | 66 | 49 | 52 | 34 | 48 |
| | Subject 42 | 278 | 238 | 379 | 441 | 189 | 194 | 31 | 29 | 44 | 48 | 23 | 27 |
| | Subject 43 | 357 | 294 | 204 | 133 | 166 | 130 | 91 | 81 | 72 | 61 | 61 | 56 |
| | Subject 44 | 233 | 268 | 303 | 158 | 100 | 116 | 36 | 38 | 40 | 29 | 25 | 27 |
| | Subject 45 | 355 | 500 | 208 | 245 | 285 | 156 | 71 | 74 | 66 | 69 | 67 | 50 |
| | Subject 46 | 335 | 389 | 313 | 257 | 277 | 115 | 91 | 85 | 89 | 78 | 72 | 52 |

The two assumptions, homogeneity and sphericity, should be checked before statistical analysis. As the equality of variances checked, it is seen that we cannot reject that variances are equal among groups except ±2 settling time (See Appendix E). Next, sphericity assumption is checked with Mauchly's test of sphericity. Sphericity assumption holds for half of the performance measures. For the performance measures, in which sphericity assumption is violated, degrees of freedom values have to be multiplied with the epsilon values given in Appendix E.

Table 6.34. ANOVA Table for practice, material and information delay for primary performance measures

| | Dev-10-mt | | Amp-of-fluct | | Maximum Deviation from | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|
| Source | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | |
| practice | 0,00 | 0,37 | 0,00 | 0,46 | 0,00 | 0,36 | 0,00 | 0,16 |
| practice * Information | 0,09 | 0,07 | 0,87 | 0,01 | 0,52 | 0,03 | 0,06 | 0,09 |
| practice * Material | 0,06 | 0,09 | 0,19 | 0,06 | 0,24 | 0,05 | 0,04 | 0,10 |
| practice * Information * Material | 0,42 | 0,04 | 0,93 | 0,01 | 0,81 | 0,02 | 0,13 | 0,06 |
| Tests of Between-Subjects Effects | | | | | | | | |
| Intercept | 0,00 | 0,95 | 0,00 | 0,93 | 0,00 | 0,95 | 0,00 | 0,98 |
| Information Delay | 0,00 | 0,56 | 0,02 | 0,20 | 0,00 | 0,39 | 0,00 | 0,38 |
| Material Delay | 0,00 | 0,36 | 0,01 | 0,21 | 0,01 | 0,23 | 0,00 | 0,38 |
| Information * Material | 0,46 | 0,02 | 0,63 | 0,01 | 0,28 | 0,05 | 0,01 | 0,25 |

Delays, material delay and information delay, are found to be statistically significantly effective on subjects’ performances. As partial eta squared values investigated, it is seen that factors included in model explains a satisfactory percentage of variability in the data. The analysis variance for primary performance measures can be seen in Table 6.34. The analysis data for secondary performance measures can be found in Appendix E.

It is seen that performances across trials are not same for all performance measures. Additionally (practice) x (material delay) and (practice) x (information delay) interaction effects are significant for *dev-10-mt* performance measure. As seen in Figure 6.20, the lines are not parallel each other which shows a significant interaction effect. In the existence of information delay, performance improvements between trials are higher than the performance improvement in the absence of information delay. In material delay, in trial 3 and 4 performance improvement is similar in the existence and absence of material delay. But in trial 5 and 6 further improvement is observed in the existence of material delay, whereas performance remained nearly the same in the absence of material delay.

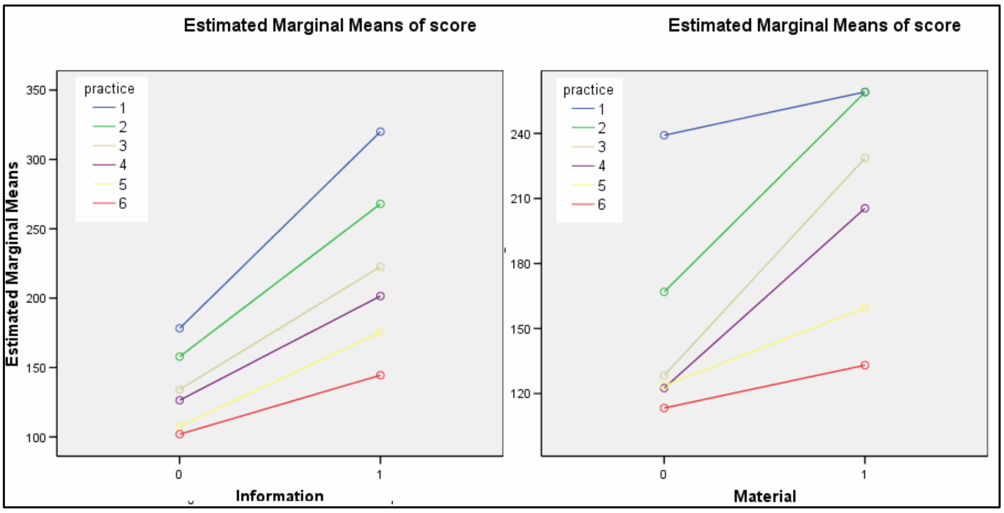



Figure 6.20. Scores in material and information delay conditions: *dev-10-mt*

Table 6.35. Pair-wise comparisons of scores obtained in trials: *dev-10-mt*

| Trial | Trial | Mean Difference | Std. Error | Significance |
|---|---|---|---|---|
| 1 | 2 | 36,22 | 18,8 | 0,07 |
| | 3 | 70,69 | 19,27 | 0 |
| | 4 | 85,16 | 18,15 | 0 |
| | 5 | 107,58 | 21,57 | 0 |
| | 6 | 125,94 | 18,83 | 0 |
| 2 | 3 | 34,47 | 18,32 | 0,07 |
| | 4 | 48,94 | 18,56 | 0,01 |
| | 5 | 71,36 | 17,92 | 0 |
| | 6 | 89,72 | 17,19 | 0 |
| 3 | 4 | 14,47 | 12,2 | 0,25 |
| | 5 | 36,89 | 15,65 | 0,03 |
| | 6 | 55,25 | 10,01 | 0 |
| 4 | 5 | 22,42 | 17,93 | 0,22 |
| | 6 | 40,78 | 12,32 | 0 |
| 5 | 6 | 18,35 | 13,04 | 0,17 |

From within subject comparisons, Practice effect is found significant for *dev-10-mt* measure. With pair-wise comparisons, it is found that performance in trial 1 is significantly worse than remaining trials. There is a significant improvement between trial 1 and trial 2. Performance again did change significantly between trial 2 and trial 3. After that point, continuous improvement is observed between consecutive trials, however differences are not significant. On the other hand, non consecutive trials are significantly different than each other, for instance trial 3 and 5, trial 4 and 6.

### 6.2.5. Effect of Pause Option

The studies conducted about decision making processes using response potentials show that decision making is the result of dynamic accumulation of activations of each alternative. When an alternative exceeds the threshold, the alternative is selected, so that decision is given. But the accumulation and exceeding the threshold need time.

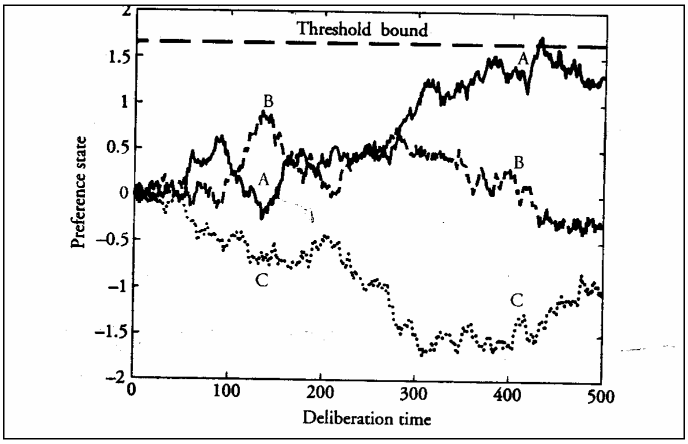



Figure 6.21. Change in preferences with respect to time (Busemeyer and Johnson, 2004)

As seen in the graph, at time t=425 alternative A exceeds the threshold and is chosen. The choice would be different if there would be a time limit on deliberation. For instance, if deliberation time is fixed at 100, then alternative B would have been chosen.

Grossler (Grossler, 1995), Gonzalez (Gonzalez, 2004) and Brehmer (Brehmer, 1990) also designed experiments to account the effect of time pressure or time limit on dynamic decision making. In some of experiments, the effect of time pressure is investigated via increasing and decreasing simulation speed. In other experiments, infinite decision period is compared with finite decision period in event driven and clock driven simulators.

To test the effect of time pressure on performance, subjects played games with pause option. Since simulation step is 0.01 and simulation length is 90 units, event-driven simulation would not be appropriate for our case. Thus, we presented the opportunity to stop the game whenever subjects want additional time to think.

Table 6.36. Scores in both-delays games with and without pause option: *dev-10-mt* and *amp-of-fluct*

| | | Deviation Area from 10 meters | | | | | | Total Amplitude of Fluctuations | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Without Pause option | Subject 41 | 342 | 300 | 153 | 198 | 96 | 134 | 83 | 66 | 49 | 52 | 34 | 48 |
| | Subject 42 | 278 | 238 | 379 | 441 | 189 | 194 | 31 | 29 | 44 | 48 | 23 | 27 |
| | Subject 43 | 357 | 294 | 204 | 133 | 166 | 130 | 91 | 81 | 72 | 61 | 61 | 56 |
| | Subject 44 | 233 | 268 | 303 | 158 | 100 | 116 | 36 | 38 | 40 | 29 | 25 | 27 |
| | Subject 45 | 355 | 500 | 208 | 245 | 285 | 156 | 71 | 74 | 66 | 69 | 67 | 50 |
| | Subject 46 | 335 | 389 | 313 | 257 | 277 | 115 | 91 | 85 | 89 | 78 | 72 | 52 |
| With pause option | Subject 47 | 128 | 124 | 233 | 137 | 122 | 109 | 32 | 54 | 55 | 43 | 37 | 40 |
| | Subject 48 | 485 | 344 | 668 | 665 | 431 | 226 | 47 | 40 | 70 | 87 | 45 | 48 |
| | Subject 49 | 145 | 287 | 211 | 116 | 150 | 106 | 58 | 70 | 65 | 43 | 37 | 32 |
| | Subject 50 | 348 | 251 | 270 | 231 | 281 | 122 | 91 | 72 | 69 | 69 | 81 | 58 |
| | Subject 51 | 312 | 337 | 252 | 308 | 204 | 262 | 86 | 84 | 71 | 75 | 70 | 71 |
| | Subject 52 | 360 | 594 | 559 | 316 | 220 | 306 | 63 | 59 | 63 | 65 | 60 | 62 |
| | Subject 53 | 216 | 107 | 139 | 240 | 141 | 193 | 43 | 29 | 50 | 56 | 33 | 42 |

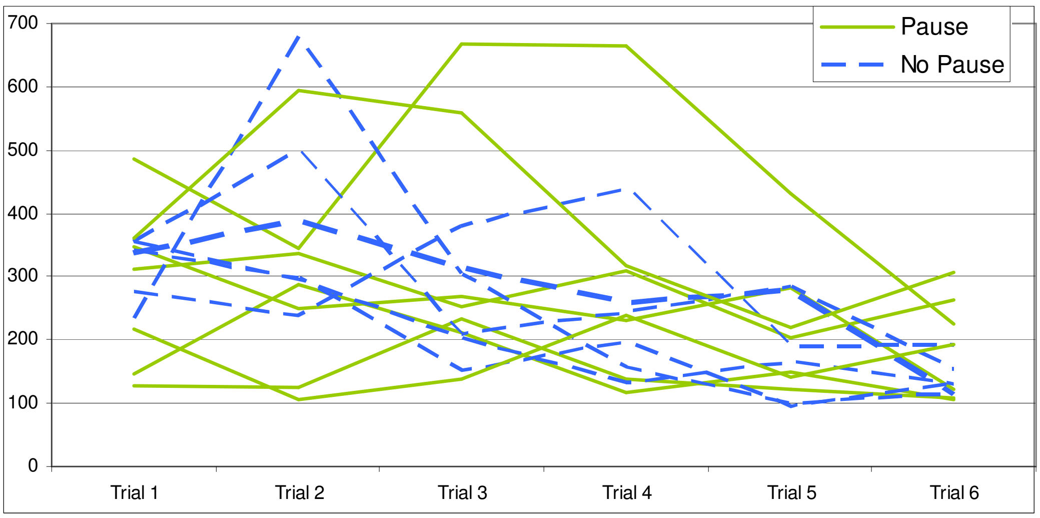



Figure 6.22. Scores in both-delays game with and without pause option: *dev-10-mt*

Figure 6.22 shows the scores obtained by the subjects in both delay games. In one of ScubaSim versions of both-delays games, subjects have the opportunity to use pause option whenever they want. The most significant difference between two groups is that the scores are highly varied in pause games. The reason for this variation is mainly due to the two subjects who had the worst scores in pause games. As we look the graphs omitting scores of these two subjects, no difference between two groups can be observed.

Starting with the statistical assumptions, for equality of error variances, with respect to some performance measures and some trials, a mild violation is observed. The results of

Levene's test can be seen in Appendix E. To check the sphericity assumption, Mauchly's test is utilized. Sphericity assumption is violated only for Caisson-RI.

Table 6.37. ANOVA Table for pause effects for primary performance measures

| | Deviation Area from 10 meters | | Total Amplitude of Fluctuations | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|
| Source | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | |
| practice | 0.00 | 0.37 | 0.00 | 0.35 | 0.00 | 0.40 | 0.39 | 0.09 |
| practice * Pause | 0.43 | 0.08 | 0.38 | 0.09 | 0.23 | 0.11 | 0.20 | 0.12 |
| Tests of Between-Subjects Effects | | | | | | | | |
| Intercept | 0.00 | 0.89 | 0.00 | 0.93 | 0.00 | 0.96 | 0.00 | 1.00 |
| Pause | 0.68 | 0.02 | 0.85 | 0.00 | 0.70 | 0.01 | 0.57 | 0.03 |

As between subjects variation is analyzed, it is seen that there is not a significant difference between two groups. As mentioned in pause game analysis, subjects do not prefer to use pause option, since they did not need or did not find it useful. Thus, it is natural that there is not a significant difference between groups.

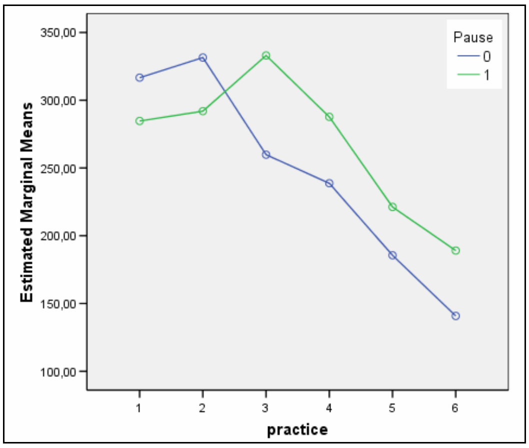



Figure 6.23. Scores with and without pause option: *dev-10-mt*

Continuing with practice effect, it is found to be significant for all performance measures. Next, performance patterns of subjects are analyzed. As seen in Figure 6.23 and Table 6.38, in both groups, subjects' performances remain in the same levels for the first 4 trials. There observed a significant performance improvement in the $5^{th}$ trial.

Table 6.38. Pair-wise comparison of scores obtained in each trial: *dev-10-mt*

| Trial | Trial | Mean Difference | Std. Error | Sgnificance |
|---|---|---|---|---|
| 1 | 2 | -11,04 | 32,19 | 0,74 |
| | 3 | 4,25 | 34,03 | 0,90 |
| | 4 | 37,45 | 30,70 | 0,25 |
| | 5 | 97,27 | 17,47 | 0,00 |
| | 6 | 135,72 | 23,71 | 0,00 |
| 2 | 3 | 15,29 | 40,36 | 0,71 |
| | 4 | 48,49 | 49,50 | 0,35 |
| | 5 | 108,31 | 34,66 | 0,01 |
| | 6 | 146,76 | 31,41 | 0,00 |
| 3 | 4 | 33,20 | 27,93 | 0,26 |
| | 5 | 93,02 | 33,31 | 0,02 |
| | 6 | 131,47 | 37,26 | 0,00 |
| 4 | 5 | 59,81 | 29,13 | 0,06 |
| | 6 | 98,27 | 35,53 | 0,02 |
| 5 | 6 | 38,45 | 27,81 | 0,19 |

As mentioned, subjects did not prefer to use pause option which makes the statistical analysis futile. A simple important conclusion is that in a clock-driven simulation subjects do not want to lose the continuity with using pause option. A better model should be formed where time pressure is decreased.

### 6.2.6. Scuba Diving Experience

Games can be used for teaching basic dynamics of real systems. For instance, subjects who get stock management experience in games will be acquainted with negative effects of delays in receiving orders and bullwhip effect. Additionally, a simulation model which is developed to solve an existing problem in real life can be used to get insight of dynamics by subjects who are experiencing problems. Thus, subjects may get experience in simulation environment which is a model of real life.

From a different perspective, it is hypothesized that subjects who have real life experience will perform better than the subjects who have not any real life experience within the modeled environment. To test the hypothesis, performances obtained by scuba divers and non scuba divers in no delay game are compared.

Figure 6.24 shows the individual scores obtained by subjects in no delay game. It is not possible to separate scuba divers from non-scuba divers. Some scuba diver and non scuba divers performed better than other subjects in their group. Thus, a scuba-non scuba division is not possible but subjects can be divided into two groups depending on their performances. However, this performance difference is not observed from third trial. Subjects who are not successful in the first two trials improved their performances and performed as good as other subjects who performed satisfactorily from the first trial.

Table 6.39. Scores obtained in no delay games by scuba and non scuba divers: d*ev-10-mt* and *amp-of-fluct*

| | | Deviation Area from 10 meters | | | | | | Total Amplitude of Fluctuations | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No delay | Subject 17 | 86 | 76 | 69 | 83 | 126 | 82 | 39 | 36 | 13 | 23 | 14 | 21 |
| | Subject 18 | 238 | 195 | 131 | 84 | 150 | 69 | 65 | 65 | 53 | 38 | 49 | 40 |
| | Subject 19 | 72 | 88 | 61 | 72 | 59 | 68 | 33 | 17 | 18 | 30 | 21 | 30 |
| | Subject 20 | 216 | 137 | 40 | 50 | 37 | 52 | 43 | 31 | 16 | 19 | 18 | 18 |
| | Subject 21 | 204 | 121 | 71 | 140 | 93 | 179 | 58 | 47 | 39 | 53 | 34 | 22 |
| | Subject 22 | 84 | 89 | 47 | 56 | 33 | 67 | 33 | 25 | 17 | 22 | 13 | 19 |
| | Subject 23 | 296 | 255 | 99 | 88 | 77 | 56 | 83 | 69 | 33 | 30 | 29 | 14 |
| | Subject 24 | 44 | 73 | 52 | 71 | 78 | 55 | 16 | 13 | 10 | 15 | 22 | 17 |
| Scuba Divers | Subject 54 | 111 | 68 | 61 | 28 | 70 | 41 | 36 | 30 | 17 | 10 | 18 | 18 |
| | Subject 55 | 66 | 40 | 28 | 21 | 18 | 34 | 16 | 17 | 13 | 7 | 7 | 19 |
| | Subject 56 | 103 | 42 | 50 | 36 | 51 | 51 | 27 | 15 | 13 | 10 | 13 | 12 |
| | Subject 57 | 120 | 105 | 156 | 87 | 74 | 59 | 42 | 46 | 45 | 38 | 35 | 30 |
| | Subject 58 | 212 | 291 | 115 | 145 | 67 | | 57 | 66 | 37 | 37 | 28 | |
| | Subject 59 | 187 | 142 | 74 | 145 | 114 | 131 | 64 | 47 | 34 | 55 | 42 | 46 |

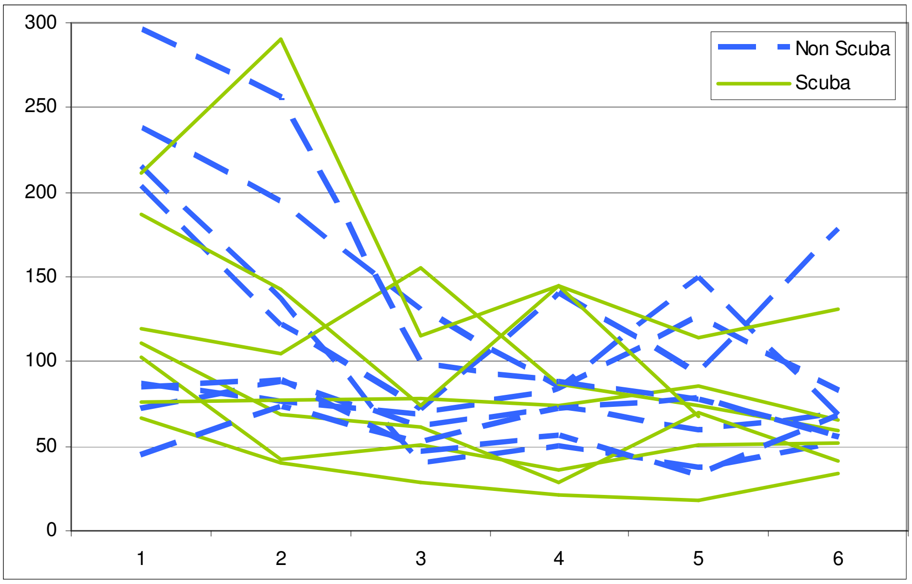



Figure 6.24. Scores obtained in no delay game by scuba divers and non scuba divers: *dev-10-mt*

Before discussing statistical analysis between subjects and within subjects, model assumptions are checked. Results of Levene's test of equality of error variances over groups shows that variance differences between groups are significant for some trial and some performance measure. But a strong violation of equality of variances is not observed. Continuing with sphericity assumption, it is observed that for all performance measures sphericity assumption does not hold at 0.1 significance level. Thus, degrees of freedom values will be adjusted with the epsilon values (Appendix E).

Starting from between subject variation, real diving experience is not found to be effective on the performance of subjects for all performance measure except *dev-mean-10mt* performance measure. Continuing with practice effect, practice effect is found to be significant for all performance measures whereas (practice) x (scuba) interaction effect is not significant. Performance is statistically differs among trials but the pattern of performance change is independent of scuba diving experience. Thus, subjects have similar learning patterns.

Table 6.40. ANOVA Table for scuba diving experience for primary performance measures

| | Deviation Area from 10 meters | | Total Amplitude of Fluctuations | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|
| Source | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | |
| practice | 0 | 0,35 | 0 | 0,44 | 0,03 | 0,19 | 0 | 0,28 |
| practice * Scuba | 0,62 | 0,06 | 0,6 | 0,06 | 0,37 | 0,09 | 0,52 | 0,07 |
| Tests of Between-Subjects Effects | | | | | | | | |
| Intercept | 0 | 0,86 | 0 | 0,83 | 0 | 0,8 | 0 | 0,8 |
| Scuba | 0,32 | 0,09 | 0,65 | 0,02 | 0,34 | 0,08 | 0,49 | 0,05 |

Next, differences between trials and between two groups are examined for *dev-10-mt* and *amp-of-fluct* performance measures. The graph on the left shows the results of *dev-10-mt* where the graph on the right shows mean scores obtained with respect to *amp-of-fluct*. When the patterns of obtained scores investigated for each group, it is seen that although scuba divers perform better than non scuba divers, the difference between two groups is not significant. Their scores are almost parallel to each other. Non scuba divers increase their performance at first three trials and they protected this high performance over the remaining trials. On the other hand, scuba divers experienced a mild performance increase during the first three trials and protect their performance at that level.

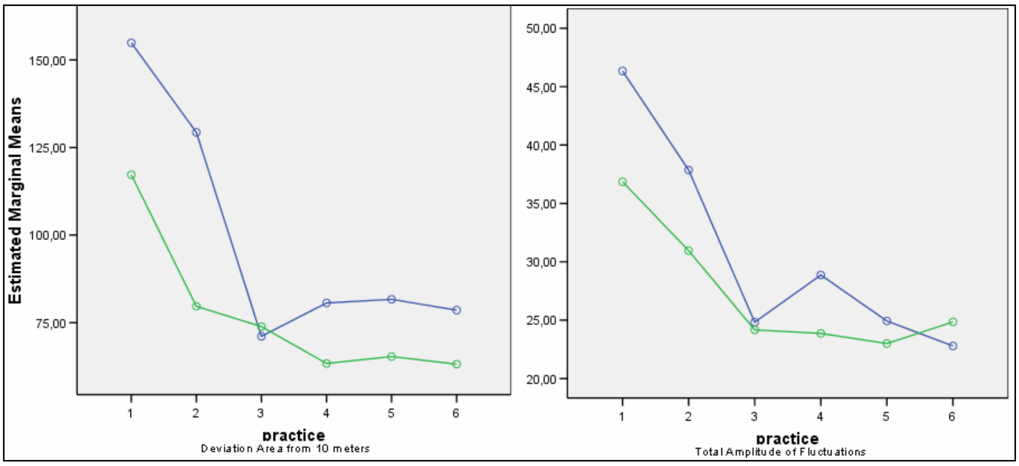



Figure 6.25. Mean scores of scuba divers and non scuba divers: *dev-10-mt* and *amp-of-fluct*

It would be a valuable search to account the differences between two groups in the last three trials with respect to *dev-10-mt* performance measure. There is a 25 points difference between two groups. The reason for this difference may be due to initial scores that each group had. Initially non scuba divers' mean performance was bad and their mean score is around 150 in the first two trials. They made a great improvement and mean score became 75. After that point, they might have thought that further improvement is not possible or they might have found themselves enough successful. On the other hand, scuba divers' scores in the last three trials are really good. Although subjects can have score as low as 17, scuba divers mean scores at the last three trials are around 50. The reasons might be further improvement is not as easy as initial improvement and they might also thought that their performance is good enough.

Table 6.41. Pair-wise comparisons of scores obtained in no delay game: *dev-10-mt*

| practice | practice | Mean Difference | Std. Error | Significance |
|---|---|---|---|---|
| 1 | 2 | 31,56 | 10,05 | 0,01 |
| | 3 | 63,57 | 20,28 | 0,01 |
| | 4 | 64,07 | 20,58 | 0,01 |
| | 5 | 62,58 | 21,55 | 0,01 |
| | 6 | 65,21 | 22,43 | 0,01 |
| 2 | 3 | 32,00 | 13,26 | 0,03 |
| | 4 | 32,51 | 15,31 | 0,06 |
| | 5 | 31,01 | 15,89 | 0,08 |
| | 6 | 33,64 | 18,95 | 0,10 |
| 3 | 4 | 0,51 | 11,44 | 0,97 |
| | 5 | -0,99 | 9,67 | 0,92 |
| | 6 | 1,64 | 14,88 | 0,91 |
| 4 | 5 | -1,50 | 9,57 | 0,88 |
| | 6 | 1,13 | 5,86 | 0,85 |
| 5 | 6 | 2,63 | 12,12 | 0,83 |

The other thing to be mentioned is that the two lines are nearly parallel each other which shows that there is not a significant (practice) x (scuba diving experience) interaction effect.

When pair-wise comparisons made between trials, it is seen that scores obtained in trial 1 and 2 are significantly different than scores obtained in trials 3, 4, 5 and 6, whereas they are not significantly different from each other.

### 6.3. Conclusion for Repeated Measures Experiments

The repeated measure analysis is conducted in two stages. In the first stage, individual analysis of practice effect and differences between subjects is carried out. In the second stage, different game types are compared to examine the effects of delays, practice, game speed, prior diving experience and their interaction effects.

There are significant differences between subjects playing no delay, material delay and pause-option games (See Table 6.42). Moreover, there are performance differences between scuba divers. Additionally, significant differences are observed between subjects playing in information delay and both-delays games with respect to *amp-of-fluct* and *max-dev-10* measures. However, differences between subjects become insignificant with respect to *dev-10-mt* and *±2 settling time* measures. As mentioned in primary performance measures sub-section, *dev-10-mt* and *amp-of-fluct* measures evaluate different characteristics of stability. The insignificance of differences between subjects with respect to *dev-10-mt* can be explained with the mentioned distinction.

Table 6.42 Significance of subject effect in different type of games

| | Dev-10-mt | Amp-of-fluct | Max-dev-10 | ±2 settling time |
|---|---|---|---|---|
| No Delay | 0.00 | 0.00 | 0.00 | 0.02 |
| Material Delay | 0.00 | 0.00 | 0.04 | 0.01 |
| Information Delay | 0.34 | 0.02 | 0.02 | 0.29 |
| Both Delays | 0.48 | 0.00 | 0.08 | 0.45 |
| Pause | 0.00 | 0.00 | 0.00 | 0.05 |
| Scuba | 0.00 | 0.00 | 0.00 | 0.00 |

Next, performance improvement patterns are analyzed with respect to dev-10-mt (See Table 6.43). It is observed that performances are improved by practice through trials in different game types. A significant performance improvement is observed at the 3rd trial in no delay games and the level of success is preserved in the remaining trials but no further improvement is observed. Scuba divers also played no delay games and performance improvement patterns through trials in no delay games played by scuba divers and non scuba divers are exactly the same. Additionally, in scuba divers-non scuba divers comparison, diving experience is found insignificant.

Table 6.43. Pair-wise comparison of trials in different game types: *dev-10-mt*

| | Prob > \|t\| | | | | | |
|---|---|---|---|---|---|---|
| Trial | No Delay | Material Delay | Information Delay | Both Delay | Pause | Scuba |
| 1 vs 2 | 0.27 | 0.58 | 0.01 | 0.73 | 0.88 | 0.40 |
| 1 vs 3 | 0.00 | 0.87 | 0.00 | 0.19 | 0.34 | 0.02 |
| 1 vs 4 | 0.00 | 0.29 | 0.00 | 0.08 | 0.95 | 0.01 |
| 1 vs 5 | 0.00 | 0.02 | 0.00 | 0.00 | 0.21 | 0.00 |
| 1 vs 6 | 0.00 | 0.01 | 0.00 | 0.00 | 0.06 | 0.02 |
| 2 vs 3 | 0.01 | 0.69 | 0.65 | 0.10 | 0.41 | 0.12 |
| 2 vs 4 | 0.04 | 0.60 | 0.34 | 0.04 | 0.93 | 0.08 |
| 2 vs 5 | 0.04 | 0.06 | 0.36 | 0.00 | 0.16 | 0.03 |
| 2 vs 6 | 0.03 | 0.03 | 0.19 | 0.00 | 0.05 | 0.10 |
| 3 vs 4 | 0.68 | 0.36 | 0.61 | 0.62 | 0.37 | 0.86 |
| 3 vs 5 | 0.64 | 0.02 | 0.63 | 0.09 | 0.03 | 0.48 |
| 3 vs 6 | 0.74 | 0.01 | 0.38 | 0.01 | 0.01 | 0.88 |
| 4 vs 5 | 0.96 | 0.16 | 0.98 | 0.22 | 0.19 | 0.59 |
| 4 vs 6 | 0.93 | 0.09 | 0.70 | 0.03 | 0.06 | 0.98 |
| 5 vs 6 | 0.89 | 0.77 | 0.68 | 0.30 | 0.52 | 0.59 |

In material delay games, performance in the first four trials remains the same. Performance improvement is observed in the 5th trial and the level is preserved in the 6th trial. In information delay games, performance in 1st trial is very poor. At the second trial, performance improvement is observed and the level is preserved in the remaining trials. In both-delays game without pause option, a significant improvement is observed in 3rd trial and in the following trials further improvement is observed. Both-delays game is also played with pause option. Performances in the first five trials do not different than each other, but at the last trial a significant improvement is observed. Moreover, in both-delay games, effect of pause option is found insignificant.

Table 6.44. Significance of material delay, information delay, practice, prior scuba diving experience and their interaction effects

| | Deviation Area from 10 meters | Total Amplitude of Fluctuations | Maximum Deviation from 10 meters | ±2 settling time |
|---|---|---|---|---|
| Practice | significant | significant | significant | significant except pause-no pause comparison |
| Practice x Material Delay | only in no delay-both delays comparison | not significant | not significant | significant |
| Practice x Information Delay | only in no delay-both delays comparison | not significant | not significant | significant |
| Practice x Delay Type | not significant | not significant | not significant | significant |
| Practice x Pause | not significant | not significant | not significant | not significant |
| Practice x Scuba | not significant | not significant | not significant | not significant |
| Material Delay | significant | significant | significant | significant |
| Information Delay | significant | significant | significant | significant |
| Material x Information | not significant | not significant | not significant | significant |
| Delay Type | significant | significant | significant | significant |
| Pause | not significant | not significant | not significant | not significant |
| Scuba Diving | not significant | not significant | not significant | not significant |

In no delay - material delay comparison, practice and material delay effects are significantly effective on performance. Although, in individual analysis of no delay and material delay games, performance improvement patterns are different, (practice) x (material delay) interaction effect is not statistically significant except *±2 settling time*. Similar results are obtained in no delay - information delay comparison. Practice and information delay effects are significant, whereas (practice) x (information delay) interaction effect is not significant except *± 2 settling time*. In no delay, material delay and information delay comparison, practice effect is again found statistically significant. Additionally, scores obtained material and information delay games are found statistically different than no delay games. However, there is no significant difference between material and information delay games. When both-delays games are added to last comparison, it is seen that both material delay and information delay are significant whereas their interaction effect is not except *± 2 settling time*. Additionally, practice effect is also significant. (Practice) x (material delay) and (practice) x (information delay) interaction effects are significant with respect to *dev-10-mt* and *±2 settling time* in no delay- both delays comparison. Thus, we can say that improvement patterns are affected by the existence of material delay or information delay with these two performance measures (See Table 6.44).

As the game results of subjects are investigated, it is seen that more than 70 percent of the output behaviors consists oscillations (at least two complete cycles with 4-5 mt amplitudes in 90 seconds simulation time). This percentage is lower in the games without delays. However, in material delay, information delay and especially both-delays games, avoiding oscillations becomes an exception. In other words, most of the behaviors observed in delayed games can be classified as oscillatory (See Appendix F).

### 6.4. Post Game Questionnaire Results

Each subject answers the questionnaire after their first and last trials. In this section, the results of these questionnaires will be presented and discussed. Subjects' perceptions about the game will be shown via these questionnaire results.

In the third question, subjects are asked to select and state reasons of their difficulties. The distribution of reasons with respect to game type can be seen in Table 6.45. Complexity of conceptually coming up with proper decisions, due to several interacting factors explained in the manual is chosen 42 times. It is followed by game speed, weak PC game playing skills and existence of delays. It has to be mentioned that delays is not presented as an option but subjects state independently that existence of delays is a difficulty factor.

Table 6.45. Distribution of factors attributed by subjects to the difficulties of obtaining successful results

| | 10 mt | | Surface | | No delay | | Material | | Information | | Both | | Pause | | Scuba | | All | | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | |
| Complexity of slider | 2 | 2 | 1 | 0 | 2 | 2 | 2 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 2 | 9 | 9 | **18** |
| Speed of the game | 1 | 4 | 4 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 15 | 13 | **28** |
| Weak PC game skills | 2 | 1 | 2 | 1 | 1 | 0 | 2 | 1 | 3 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 14 | 9 | **23** |
| Several interacting factors | 3 | 3 | 2 | 1 | 2 | 3 | 4 | 3 | 3 | 1 | 3 | 3 | 2 | 3 | 3 | 3 | 22 | 20 | **42** |
| Hidden/unknown factors | 2 | 1 | 1 | 1 | | | 1 | 1 | 4 | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 9 | 7 | **16** |
| Other-Delay | 1 | 3 | 3 | 3 | | | 1 | 1 | | 1 | 2 | 2 | 4 | 4 | 1 | 0 | 12 | 14 | **26** |
| Other-Constant flow | | | | | | | | | 1 | 1 | 1 | 1 | | | | | 2 | 2 | **4** |

Subjects also chose hidden/unknown factor 16 times which can be related to the fourth question in the questionnaire. Subjects are asked whether they think there were any external factors/forces like currents, winds, unstable regions in water or any other random factors during the game. In 25 of the answers subjects state that there are external factors for sure, while another 25 of the answers state that there may be some external forces. Since the question is answered 118 times, we can say that almost half of the subjects perceive that there are external forces and almost one fifth of the subjects state these unknown factors as a reason for their difficulties in obtaining successful results.

Subjects are also expected to decide whether any additional information would increase their success in the game. Velocity, air volume and force data are enumerated for selection and subjects are able to select more than one option. In 47, 64 and 46 of 118 questionnaires, subjects chose velocity, air volume and force data respectively.

# 7. CONCLUSION AND FURTHER RESARCH

The world we live in is dynamic and complex in nature, consisting delayed feedbacks and non-linearities. But, human beings are not equipped to make optimum decisions in such environments. Moreover, we often do not have enough time to analyze the system structure. Delays, non-linearities and time pressure cause people behave sub optimally. In this thesis, effects of time delays and time pressure on decision performance and performance improvement with practice in a non-linear dynamic feedback environment are analyzed. For the analysis, Latin Square Experiments and Repeated Measures Experiments are carried out.

In Latin Square experimental design, the negative effect of delay is found to be highly significant. In repeated measures experiments, delay structures are added to basic structure one by one: material delay, information delay and both delays. It is found that material delay and information delay have significant effects on performance. However, their interaction effect is not significant which shows that there is an additive effect of delays. Additionally, it is observed that there is not a significant performance difference between material delay and information delay. Thus, type of delay (material/information) does not significantly affect the performance.

The effect of delay on performance improvement is found to be significant with respect to *deviation area from 10 meters* but not *total amplitude of fluctuations.* Differences between no delay and delay games decreased with practice with respect to deviation area from 10 meters. In other words, subjects playing in delayed games developed strategies necessary for these games. However, average scores of subjects in delay and no delay games stay parallel with respect to total amplitude of fluctuations measure. Thus, performance improvement patterns are not affected by the existence of delays.

Game speed (time pressure) is another game attribute found significant in Latin square experiments. Thus, an extreme case of slow game, pause option is presented in repeated measures experiments. However, subjects did not use pause option since they felt that they would lose time continuity when pause option was used. Thus, there is not a significant difference between games with and without pause option.

Another significant effect on performance is practice. In Latin square experiments, score obtained at least in one trial is significantly different than others. However, it is not possible to conclude that there is a continuous improvement pattern throughout trials. Since, the game attributes differ between successive trials in Latin Square design; it is not easy to use or modify the decision strategy used in preceding trials. In repeated measures experiments, on the other hand, the same game is played six times successively. In all game types, one or two statistically significant improvements are observed. Additionally, there is not any significant deterioration throughout the trials.

Both in Latin Square and Repeated Measures analyses, there are differences between subjects. Blocking is used to have clearer results. A specific finding about subject differences is that the effect of scuba diving experience on performance is not statistically significant. Scuba divers use fins and hands to stabilize and also they state that they make decisions depending on motion of water etc. These may be related to the insignificance result.

Among the different behavior types observed in the games, oscillations take the first place. In about 70 percent of the games, oscillations are significant. This ratio drops in games without delay structures and increases with delay structures. Although there are some exceptional subjects who avoid oscillations in delay games and others who experience oscillations in no delay games, oscillations are typical in delay games. A ratio as high as 70 percent, shows that subjects do experience a management/control problem.

As mentioned, oscillations are observed in the existence of delays. To avoid oscillation, decision makers should take into account the supply line (previously given but not yet received orders). Yasarcan showed that virtual supply line is effective in control of stocks in the existence of delays other than material delay (Yasarcan, 2004). In this study, virtual supply line decision heuristic is applied in ScubaSim and it is seen that effective stock control is possible even if in such complex environments.

One of the most interesting future research areas is modeling the decision process of subjects in this real-time dynamic decision environment. Since decisions are given continuously, it is not straightforward to determine a decision function for subjects. However, it would be interesting to explore whether heuristics applicable in discrete time decision making are also applicable in continuous time decision making.

As the game outputs are analyzed, oscillatory behaviors are observed. Even in no delay game, there are implicit delays in the structure, which may explain these oscillations. Additional delay structures, material and information delays further deteriorate performance. However, in delay games, some subjects perform similar to the behaviors obtained in no delay games. Thus, decision processes of the subjects should be analyzed more extensively to find the differences between decision strategies of subjects who can avoid oscillations and those who can not.

In this study, dynamic complexity is increased with delays, non-linearities and time pressure. The strength of feedback is also increases dynamic complexity. However, effect of strength of feedback in real-time decision environments is not studied. A further research can be conducted to analyze the effect of feedback strength on performance and learning.

Moreover, there are only two levels of game speed. It remains an unknown whether there is a linear or non-linear relationship between game speed and performance. Additional experiments in low game speed with different delay structures might reveal the relation between time pressure, performance and performance improvement.

Finally, with additions to ScubaSim, a scuba diving training simulator can be developed. For the training simulator, other control tools should be included to simulator such as fin movements.

# APPENDIX A: MODEL FORMULATION

air(t) = air(t - dt) + (air_flow - disturbance) * dt (moles)

INIT air = pressure*(90-volume_of_the_diver*1000)/RT (moles)

INFLOWS:air_flow=Air_Adjustment_Decision*normal_flow*pressure/RT (moles/sec)

OUTFLOWS: disturbance = PULSE(air/4,5,0) (moles/sec)

depth(t) = depth(t - dt) + (velocity1) * dt (meters)

INIT depth = 10 (meters)

INFLOWS:velocity1 = velocity (meter/sec)

velocity(t) = velocity(t - dt) + (acceleration) * dt (meter/sec)

INIT velocity = 0 (meter/sec)

INFLOWS: acceleration = net_force/mass (meter/sec$^2$)

Air_Adjustment_Decision = 0

density_of_diver = 1070 (kg/m$^3$)

density_of_water = 1000 (kgs/m$^3$)

drag_force = 27.2*velocity^2 (N)

drag_force_vector = IF(velocity=0)

THEN(0)

ELSE(-velocity/ABS(velocity)*drag_force) (N)

effective_depth = IF(depth<-0.5)

THEN(0)

ELSE(IF(depth<0)

THEN((0.5+depth)/2)

ELSE(depth+0.5/2)) (meters)

gravitational_constant = 9.81 (meter/sec$^2$)

lifting_force = -volume_in_water*gravitational_constant*density_of_water (N)

lt_m3_conversion_factor = 1000 (liters/meters$^3$)

mass = 90 (kgs)

net_force = weight+lifting_force+drag_force_vector (N)

normal_flow = 1 (liters/sec)

pressure = 1+effective_depth/10 (atm)

RT = 25 (atm/(liters*moles))

volume_BC_in_water = IF(depth<-0.5)

THEN(0)

ELSE(IF(depth<0)

THEN(volume_m3*(0.5+depth)/0.5)

ELSE(volume_m3)) ($m^3$)

volume_of_diver_in_water = IF(depth<-1.5)

THEN(0)

ELSE(IF(depth<0)

THEN(volume_of_the_diver*(1.5+depth)/1.5)

ELSE(volume_of_the_diver)) ($m^3$)

volume_in_water = volume_BC_in_water+volume_of_diver_in_water ($m^3$)

volume_lt = air*RT/pressure (liters)

volume_m3 = volume_lt/lt_m3_conversion_factor ($m^3$)

volume_of_the_diver = mass/density_of_diver ($m^3$)

weight = mass*gravitational_constant (N)

# APPENDIX B: DYNAMICS OBTAINED IN DT VERIFICATION

## B.1. Heuristic 1 Results

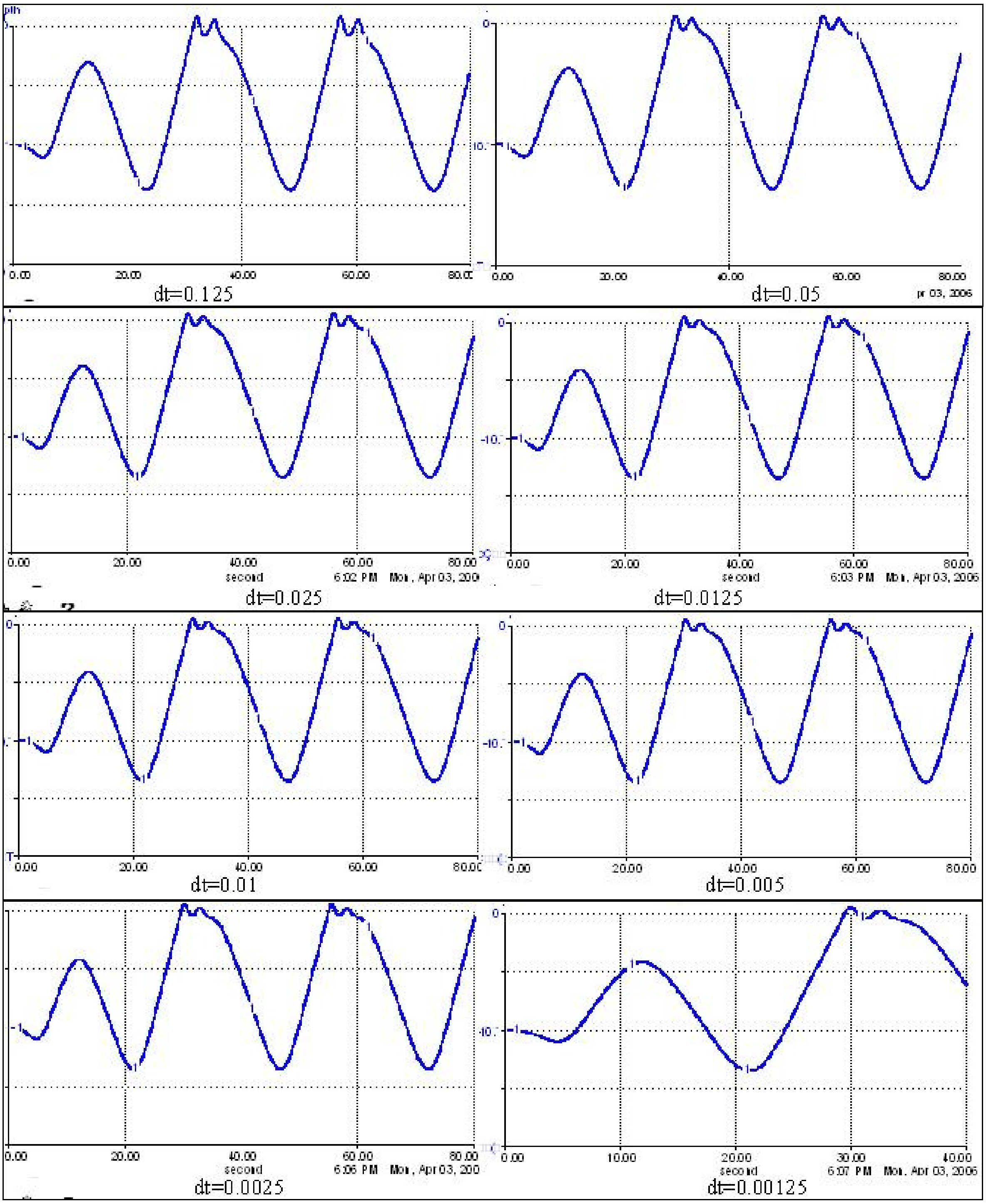



Figure B.1. Results with Euler method for Heuristic 1

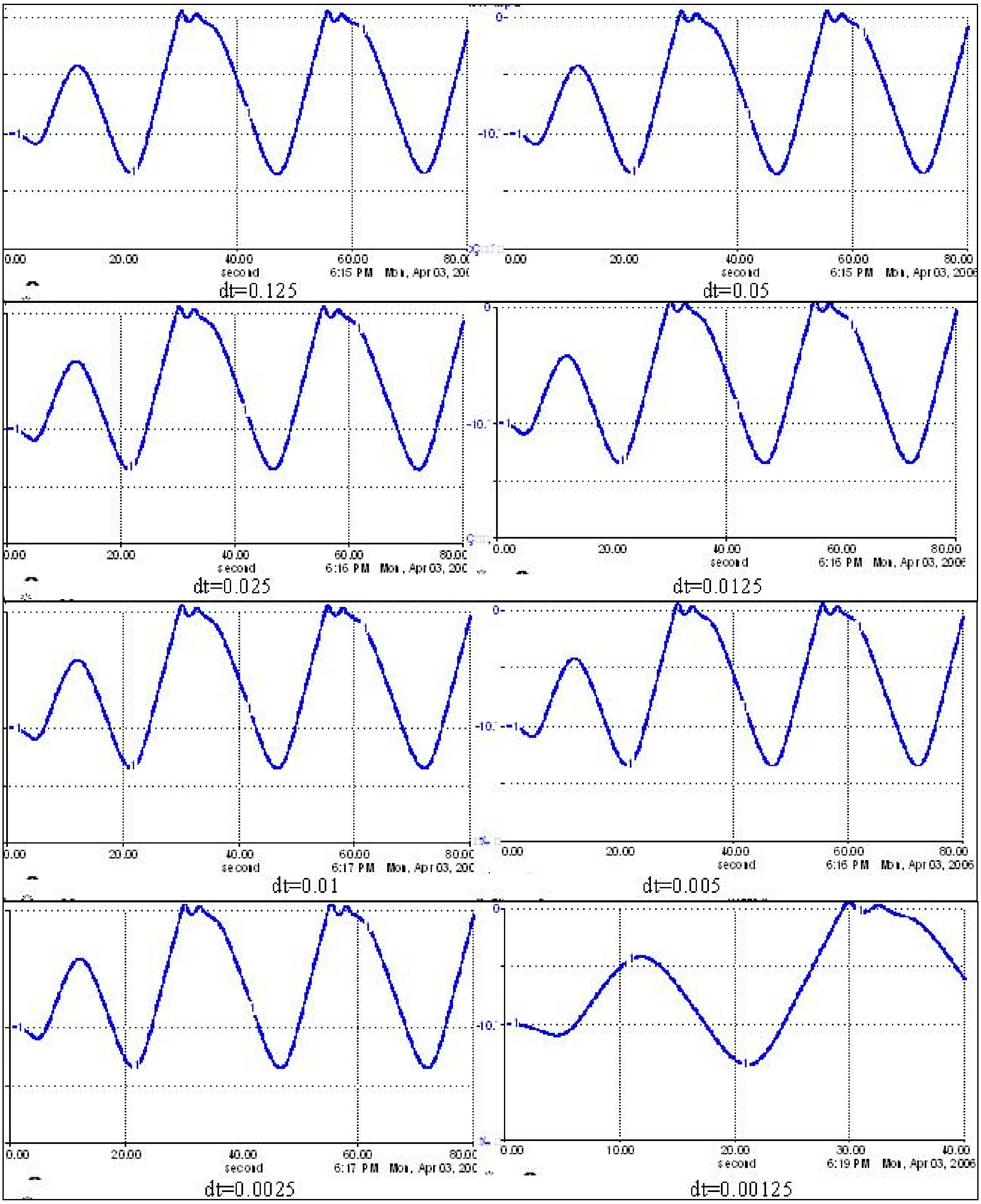



Figure B.2. Results with Runge-Kutta4 method for Heuristic 1

## B.2. Heuristic 2 Results

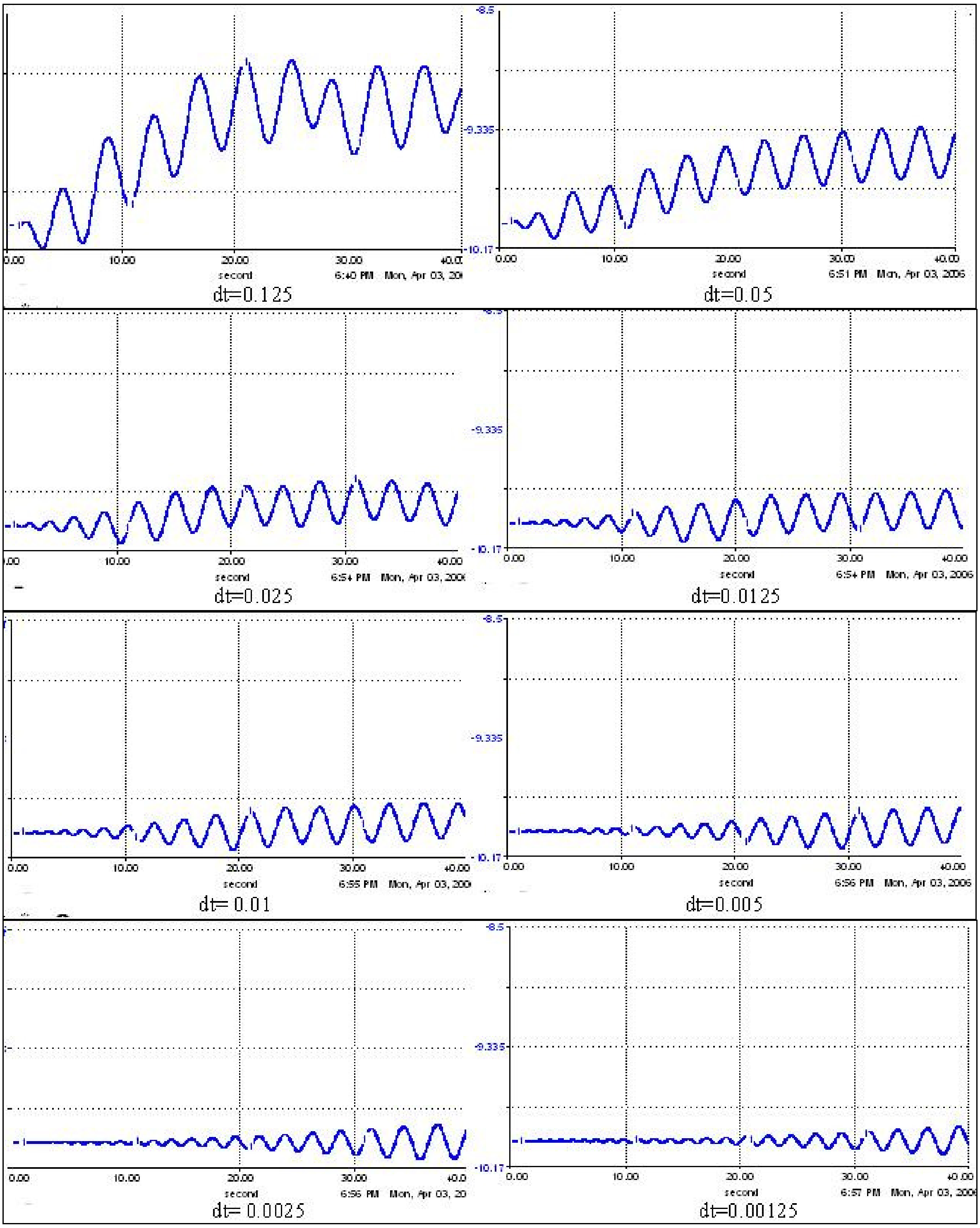



Figure B.3. Results with Euler method for Heuristic 2

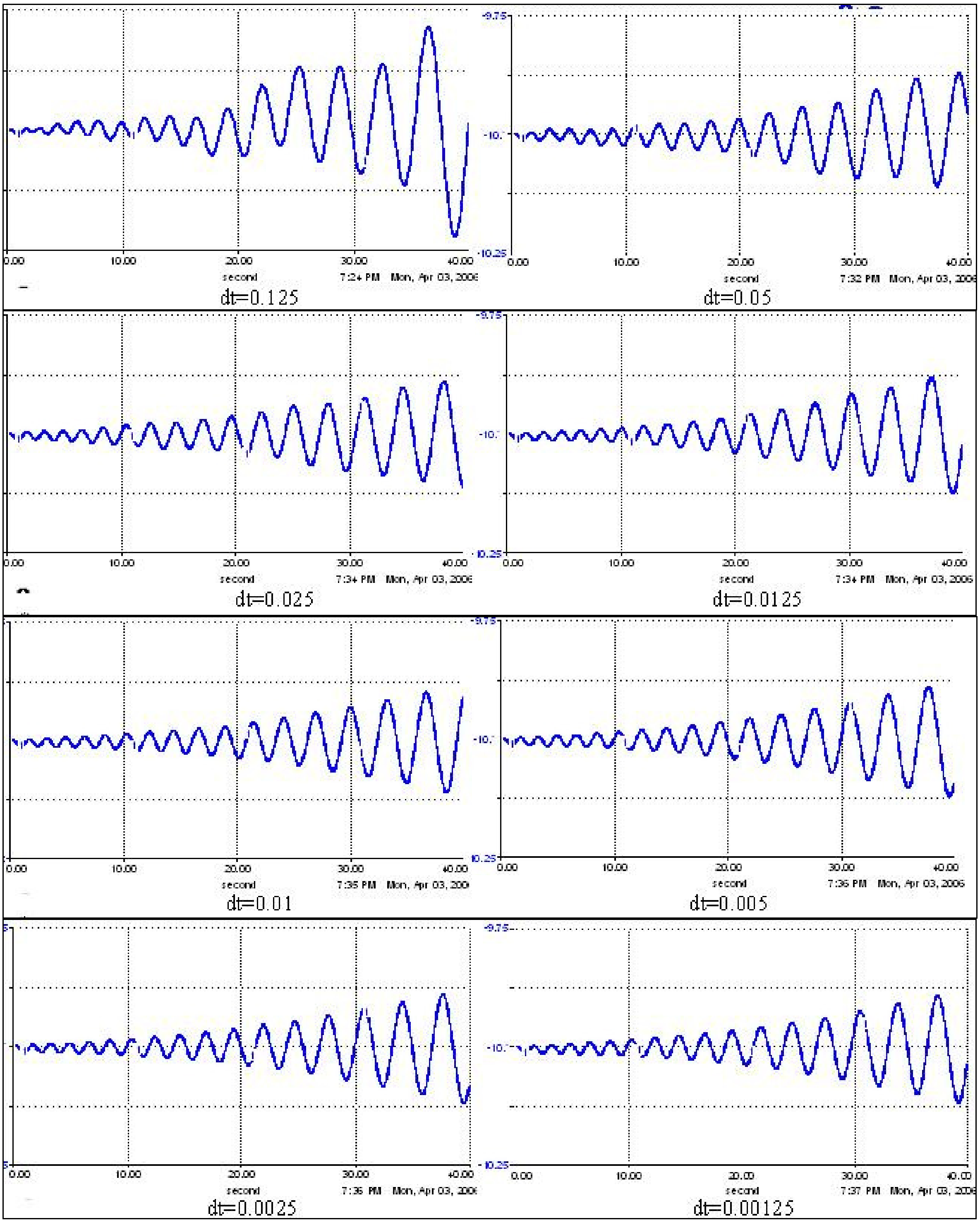



Figure B.4. Results with Runge-Kutta4 method for Heuristic 2

## B.3. Heuristic 3 Results

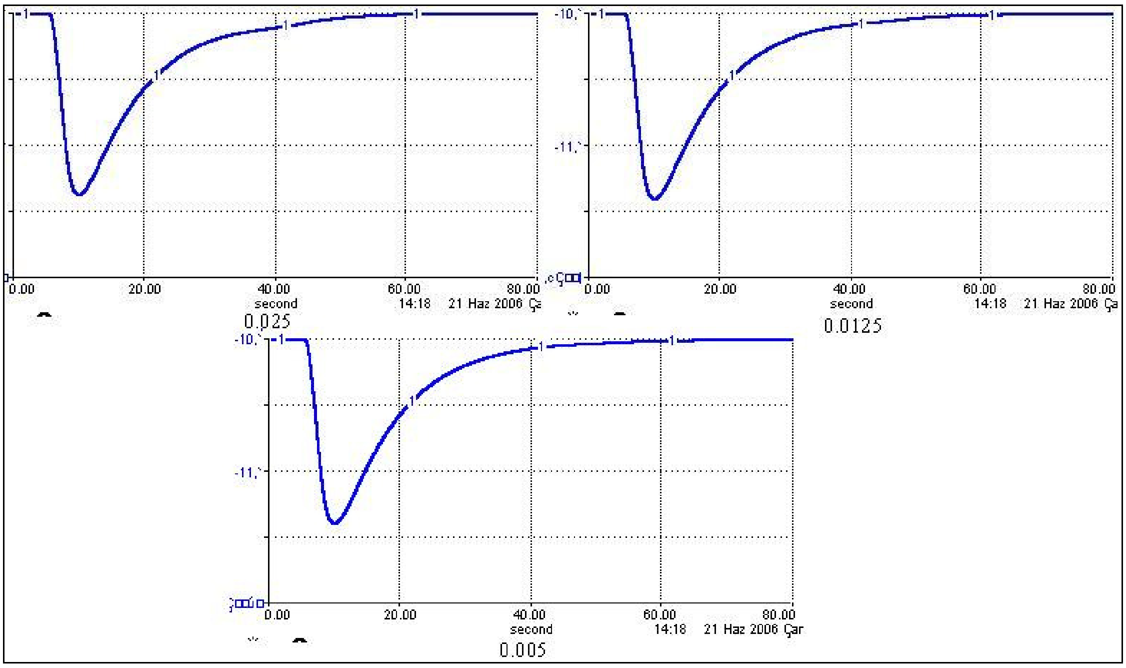



Figure B.5. Results with Euler method for dt=0.025, 0.0125 and 0.005 for Heuristic 3

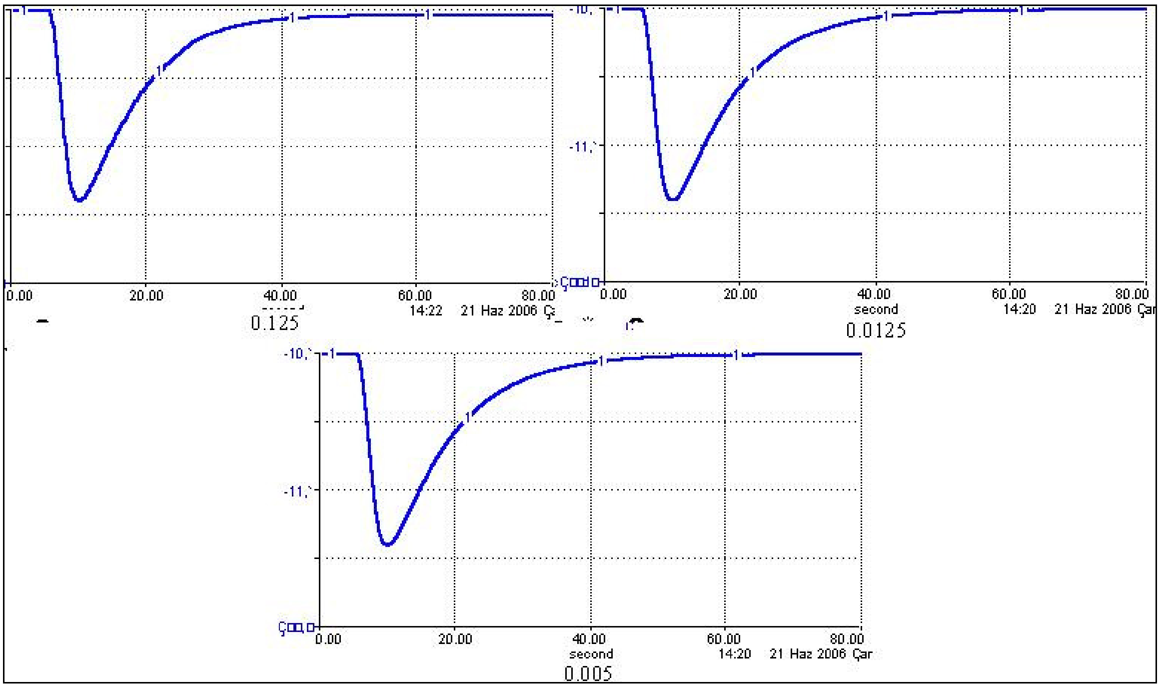



Figure B.6. Results with Runge-Kutta4 for dt=0.125, 0.0125 and 0.005 for Heuristic 3

## B.4. Real Data Results

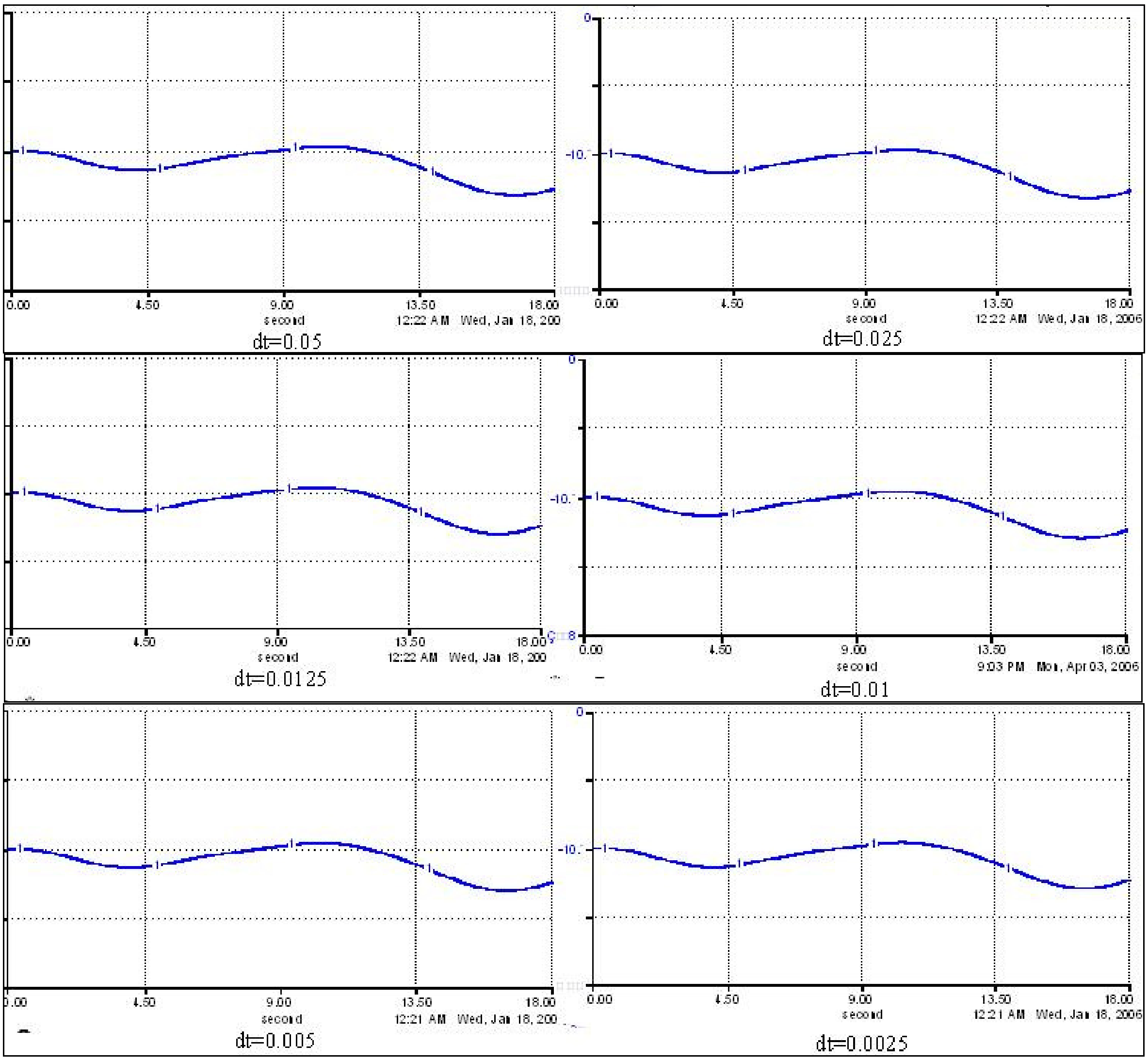



Figure B.7. Results with Euler method:18 seconds real data

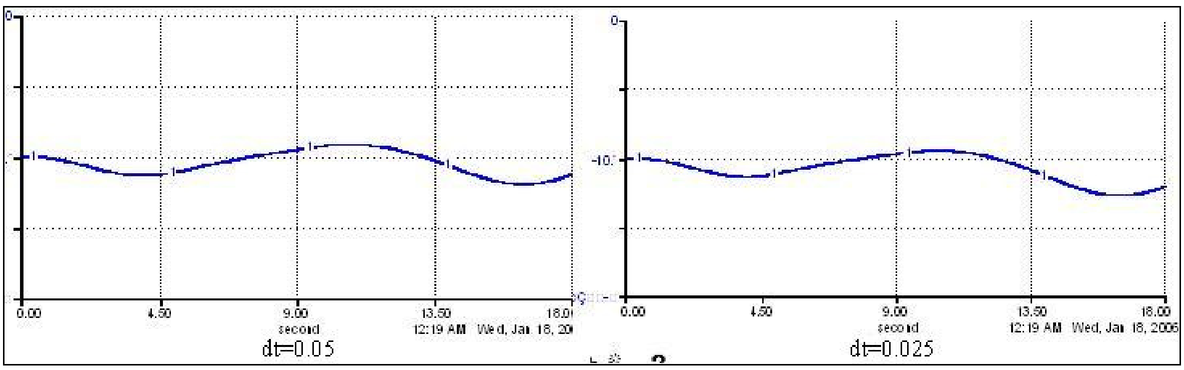



Figure B.8. Results with Runge-Kutta4 for dt=0.05 and 0.025: 18 seconds real data

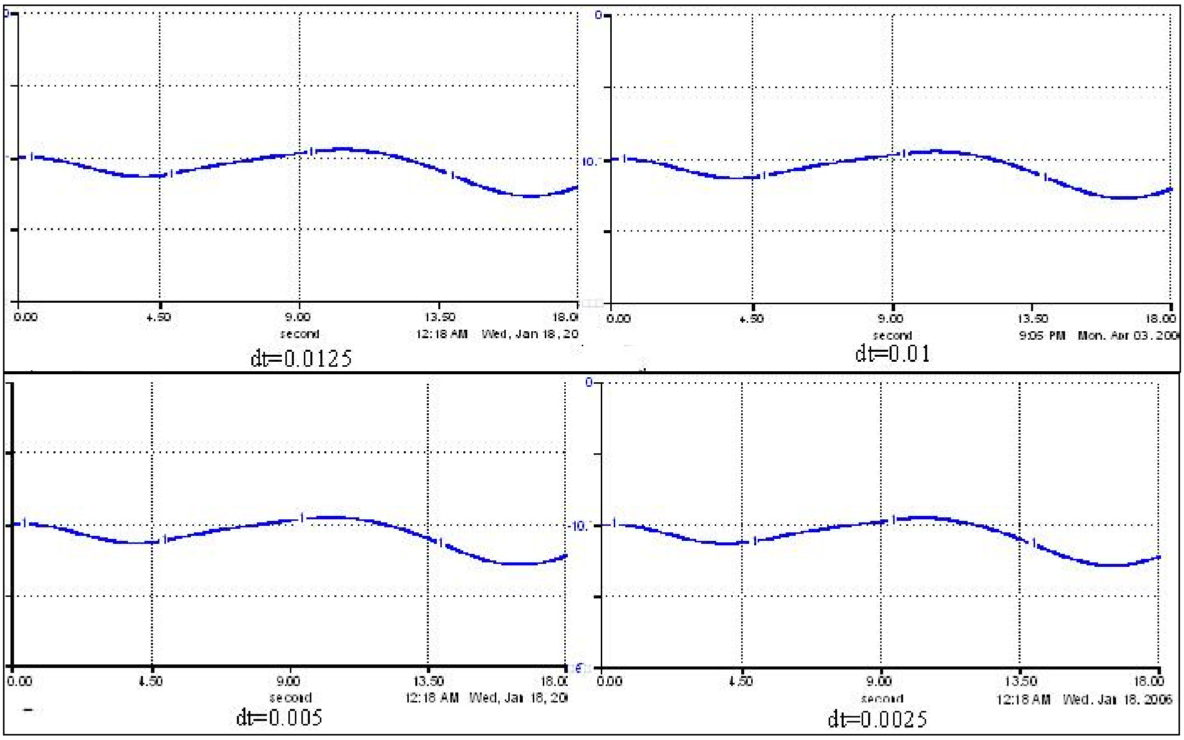



Figure B.9. Results with Runge-Kutta4 for dt=0.0125, 0.01,0.005 and 0.0025: 18 seconds real data

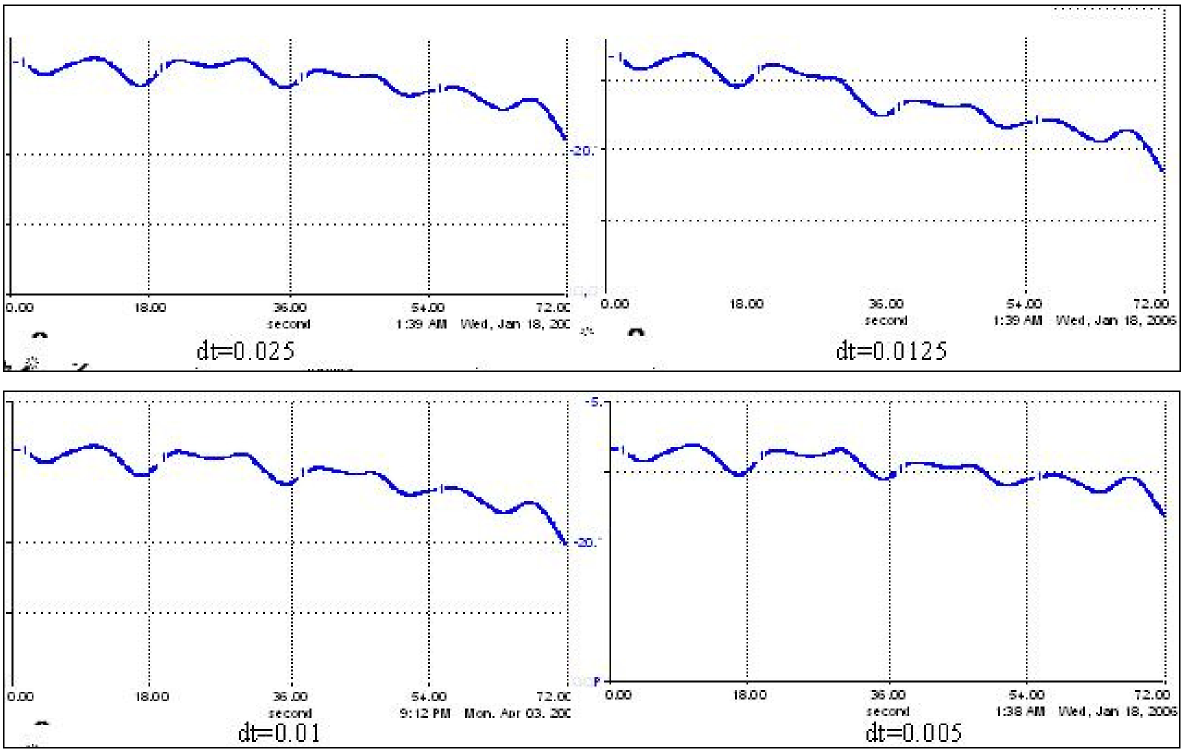



Figure B.10. Results with Euler method: smoothed real data

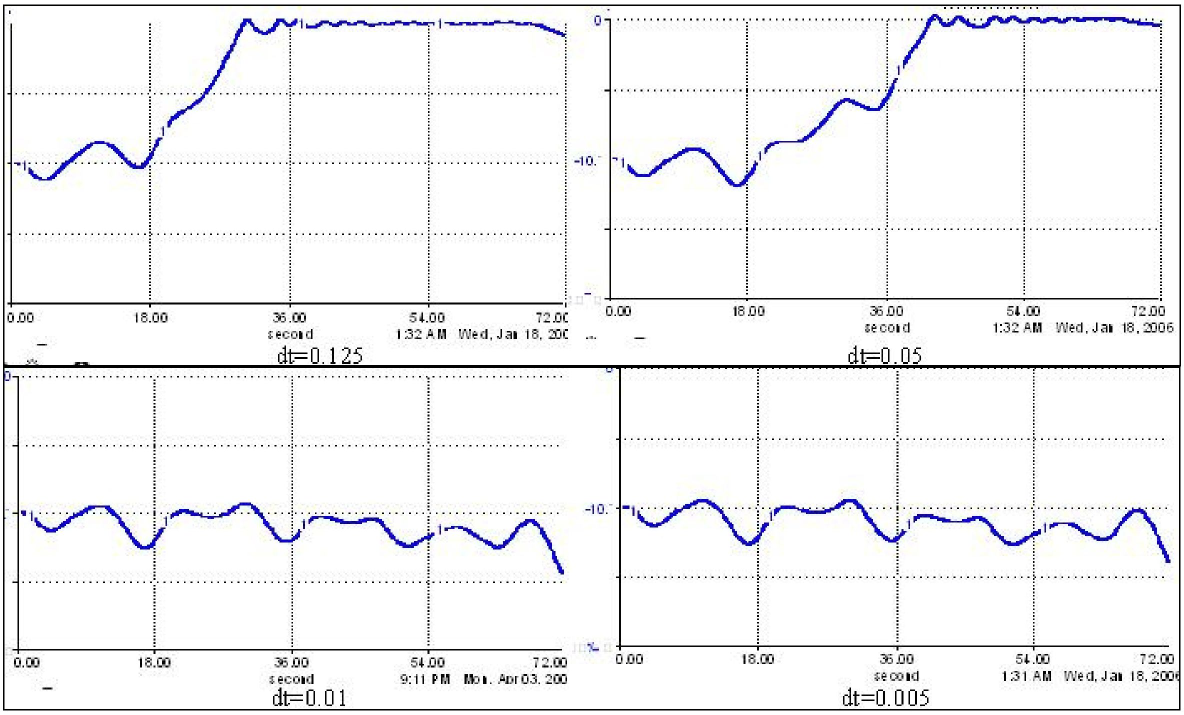



Figure B.11. Results with Runge-Kutta4: smoothed real data

# APPENDIX C: GAME BRIEFING AND QUESTINNARE

## C.1. Game Briefing

## SCUBA DIVING GAME (SCUBA-SIM)

Scuba diving game (Scuba-Sim) is an interactive dynamic simulator for scuba diving process. In the game you will be playing the role of a diver and you will try to stabilize at 10m depth, by inflating or deflating your jacket, in other words BC (buoyancy compensator).

There are three major versions of the game depending on the initial position. You may be initially at the surface or 20m depth and will try to stabilize at 10m as soon as possible. In the third version you will start at desired depth (10m) but after some time you will suddenly lose some air from your jacket which also causes to lose your stability.

You will play 8 different games in one of these three versions. These 8 games will have different difficulty levels. You may face delays in deflating and inflating and learning your depth level. Also the speed of the game will be altered in different versions. Finally, the constant flow volume (in inflating and deflating) will differ.

**About Diving:**

The motion of an object in the water is determined by three main forces; **weight** of the object, **lifting force** and **frictional force** acting on the object. The net resultant force acting on the object results in acceleration which changes the velocity of the object. The object moves with this velocity.

Direction of the $F_{friction}$ is opposite to the direction of motion and it is proportional to square of the velocity of the object.

$F_{friction} = - KV^2$ where K is determined by the viscosity and shape parameters of the fluid and object

During diving, divers manipulate the volume of the air in their BC to adjust their positions. This change in the volume of air alters the lifting force acting on diver.

The lifting force acting on an object in fluid is;

$F_{lifting} = V_{object}*d_{fluid}*g$ where $V_{object}$ is the volume in fluid of the object,
$d_{water}$ is the density of fluid
and g is gravitational constant.

By changing the volume of air in BC, divers alter the lifting force and consequently the net force acting on them. This net force causes diver to move or stabilize. Let's see the situation by examples:

If a diver, stable at any position, wants to move deeper, s/he has to deflate the BC. This will decrease the air in the BC and lifting force acting on diver. If, on the other hand, s/he wants to move towards the surface, s/he has to inflate.

Assume that diver is moving upwards and wants to change his/her velocity. If s/he deflates, velocity will decrease; diver may stop and start to move downwards if s/he deflates enough. On the other hand, while moving upwards, if diver inflates, s/he will start moving even faster than she has been, in the same direction. Finally, if the diver is moving downwards and wants to slow down or stop, s/he must inflate.

Additionally, we must mention the relation between volume and pressure of gases. The volume of gases increases as the pressure of gases decreases when temperature and mole of gas are constant.

$P_{gas} \sim 1/V_{gas}$ where $P_{gas}$ is the pressure of the gas,
And $V_{gas}$ is the volume of the gas.

The pressure acting on your BC is 1 atm on the surface and increases by 1 atm for each 10 meter depth increase. Assuming that you are moving upwards and you are neither inflating nor deflating, the volume of air in your BC will increase since the pressure acting on it will decrease. While moving downwards, the volume of air will decrease due to increase in pressure, assuming that you are neither inflating nor deflating.

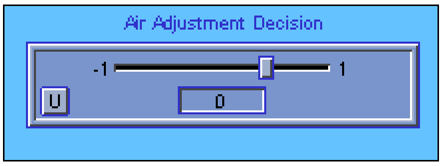
**Decisions Made by the Player:**

The goal is to stabilize at 10 m as soon as possible by altering the volume of air (altering the lifting force). You can adjust the volume of air by deflating or inflating. The deflated and inflated air volume per unit time is constant since it is done simply opening or closing the valves.

Your decision will be

- Opening the valve that purges air to deflate (-1)
- Opening the valve that pumps air to inflate (1)
- Keeping both valves closed (0)

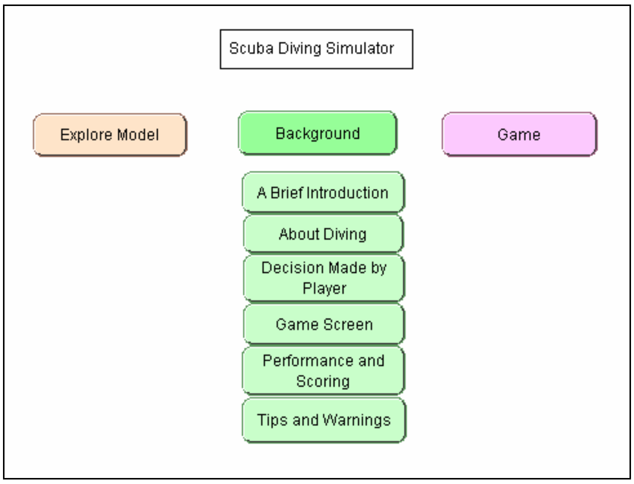
You will enter deflating/inflating decisions by the tool below. If the slider is (1), then you are inflating, if the slider shows (-1), you are deflating. Lastly, if the slider shows (0), you are neither deflating nor inflating.



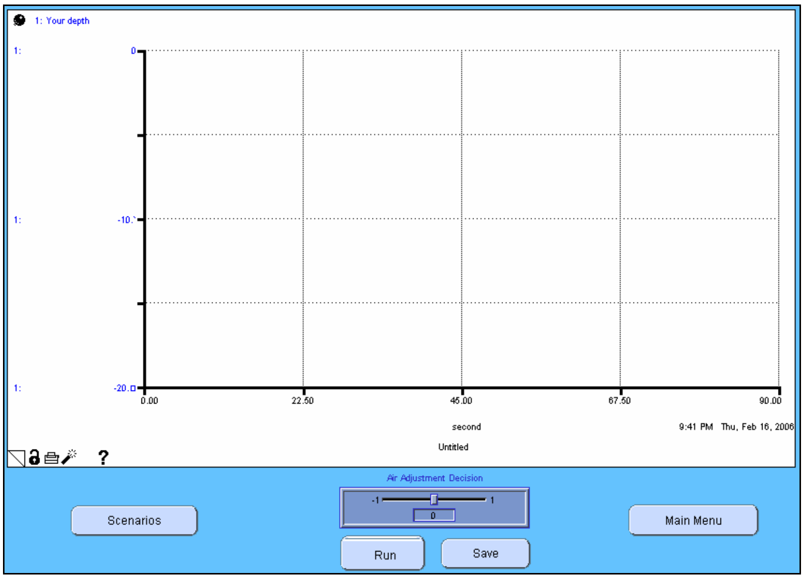

The slider is not continuous, it is discrete. In the left part it is (-1), in the right part it is (1) whereas in the middle parts it is 0. It would be better to watch the value in the small window just below the slider, to be sure about the decision made.

**Game Screen:**

In the main menu screen, you have chance to examine the model by "explore model" button, have some background information about the Scuba-Sim or may play the game if you feel comfortable with the process.




The game screen that you will face is shown in the figure below. You can observe your depth data from the position-time graph. No additional data will be given about your velocity. But you perceive the velocity information from the slope of the position-time graph.




The game will be started when you press "Run" button. As mentioned above you will use "Air Adjustment Decision" slider for your inflating/deflating decisions throughout the game.

Scenarios button is used to obtain different versions of the game. The versions of game can be classified as slow and fast depending on the speed of the simulation. Slow game will be last approximately 5 minutes, whereas fast game will last only 2.5 minutes. You can not stop the game when you press run button.

**Performance and Scoring:**

In the game you are expected to reach 10 m depth as soon as possible and stabilize at that desired level. A score will be calculated depending on the discrepancy between your position and desired depth (10m). The aim is having the minimum score. You will be paid a symbolic reward depending on your score.

**Tips and Warnings:**

Your decisions will change the volume of your BC; the volume will alter your acceleration; your acceleration will change your velocity and you will move with that velocity. So the effect of your decisions will be observed after some delay due to this physical process. It is important to take these delays into account to prevent over reactive decisions.

In some difficult versions of the game, there are delays in pumping air (before it reaches to the BC) and information delays in knowing your depth (due to reading in some depth measurement gadget).

As mentioned, the volume of air in your BC will increase when you are moving upwards and decrease when moving downwards. So, any movement even without any inflating/deflating decision will not be linear.

Keep the mouse preferably always clicked on the decision slider so as to avoid mechanical delays and panic errors.

If, by mechanical mistake, you enter erroneous decision in the slider which is just the opposite of what you are intending to enter, please call the game facilitator immediately. In this situation the game will be restarted.

Once you finished with the game, please press the **save** button.

### C.2. Post Game Questionnaire

1. Was the objective the task involved in the game clear?
2. Did you follow a specific strategy that you can describe? (Did your strategy differ in different versions of the game?)
3. If you had difficulties in obtaining successful results, do you think these difficulties are due to;
    - Complexity of mechanics of entering decisions through slider
    - Speed of the game
    - Your weak computer/video game playing skills(as in PC or Playstation games)
    - Complexity of conceptually coming up with proper decisions, due to several interacting factors/factors explained in the manual
    - Hidden/unknown difficulty factors in the game
    - Other
4. Do you think there were any external factors/forces like currents, winds, unstable regions in water or any other random factors during the game?
5. Do you find yourself successful? If not, how do you think you could improve?
6. Would any additional info increase your success in the game?
    - Velocity data
    - Air volume data
    - Force data
    - Other

# APPENDIX D: LATIN SQUARE TABLES

Table D.1. Scores of games initialized at 10 meters: amp-of-fluct measure

| | Subject1 | Subject2 | Subject3 | Subject4 | Subject5 | Subject6 | Subject7 | Subject8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | SD + Scuba1 | SD + Scuba2 | Trial i total | Game j total |
| Trial 1 | 43 | 81 | 15 | 20 | 45 | 10 | 48 | 40 | 304 | 148 |
| Trial 2 | 32 | 46 | 16 | 30 | 33 | 38 | 35 | 16 | 245 | 172 |
| Trial 3 | 29 | 50 | 23 | 57 | 38 | 28 | 22 | 32 | 279 | 268 |
| Trial 4 | 20 | 36 | 27 | 20 | 29 | 17 | 31 | 11 | 191 | 258 |
| Trial 5 | 17 | 49 | 32 | 45 | 25 | 31 | 42 | 54 | 295 | 203 |
| Trial 6 | 35 | 53 | 45 | 12 | 22 | 40 | 16 | 17 | 239 | 249 |
| Trial 7 | 54 | 19 | 13 | 19 | 23 | 9 | 40 | 21 | 197 | 240 |
| Trial 8 | 35 | 26 | 9 | 23 | 10 | 19 | 56 | 24 | 202 | 415 |
| Subject k total | 265 | 361 | 180 | 227 | 225 | 191 | 290 | 215 | 1953 | |

Table D.2. Scores of games initialized at 10 meters: Max-dev-10 measure

| | Subject1 | Subject2 | Subject3 | Subject4 | Subject5 | Subject6 | Subject7 | Subject8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | SD + Scuba1 | SD + Scuba2 | Trial i total | Game j total |
| Trial 1 | 11 | 10 | 2 | 3 | 8 | 3 | 10 | 6 | 54 | 27 |
| Trial 2 | 7 | 4 | 2 | 2 | 7 | 11 | 8 | 2 | 43 | 31 |
| Trial 3 | 7 | 6 | 4 | 7 | 10 | 10 | 3 | 2 | 50 | 57 |
| Trial 4 | 1 | 10 | 4 | 2 | 3 | 8 | 4 | 1 | 33 | 35 |
| Trial 5 | 4 | 8 | 5 | 4 | 6 | 6 | 5 | 7 | 44 | 31 |
| Trial 6 | 4 | 6 | 5 | 2 | 8 | 10 | 3 | 2 | 38 | 31 |
| Trial 7 | 7 | 2 | 2 | 2 | 2 | 2 | 5 | 3 | 25 | 47 |
| Trial 8 | 4 | 3 | 1 | 3 | 2 | 5 | 7 | 2 | 28 | 57 |
| Subject k total | 45 | 50 | 25 | 25 | 47 | 55 | 44 | 24 | 316 | |

Table D.3. Scores of games initialized at 10 meters: ±2 settling time measure

| | Subject1 | Subject2 | Subject3 | Subject4 | Subject5 | Subject6 | Subject7 | Subject8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | SD + Scuba1 | SD + Scuba2 | Trial i total | Game j total |
| Trial 1 | 90 | 90 | 16 | 42 | 90 | 90 | 90 | 90 | 597 | 334 |
| Trial 2 | 90 | 90 | 35 | 84 | 66 | 90 | 90 | 0 | 544 | 248 |
| Trial 3 | 81 | 90 | 53 | 90 | 90 | 90 | 69 | 40 | 603 | 690 |
| Trial 4 | 0 | 90 | 59 | 54 | 90 | 79 | 33 | 0 | 404 | 595 |
| Trial 5 | 45 | 90 | 78 | 79 | 90 | 90 | 86 | 90 | 648 | 385 |
| Trial 6 | 90 | 90 | 90 | 0 | 59 | 90 | 9 | 0 | 428 | 512 |
| Trial 7 | 89 | 49 | 0 | 75 | 36 | 0 | 90 | 69 | 408 | 644 |
| Trial 8 | 88 | 38 | 0 | 83 | 17 | 90 | 90 | 87 | 494 | 719 |
| Subject k total | 573 | 627 | 331 | 507 | 538 | 619 | 557 | 376 | 4127 | |

Table D.4. Scores of games initialized at 10 meters: Dev-mean-10mt measure

| | Subject1 | Subject2 | Subject3 | Subject4 | Subject5 | Subject6 | Subject7 | Subject8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | SD + Scuba1 | SD + Scuba2 | Trial i total | Game j total |
| Trial 1 | 3.1 | 3.0 | 0.4 | 0.5 | 0.2 | 1.0 | 0.3 | 0.5 | 9.0 | 3.0 |
| Trial 2 | 1.5 | 0.4 | 0.5 | 0.0 | 0.1 | 1.2 | 0.8 | 0.1 | 4.5 | 3.8 |
| Trial 3 | 1.3 | 1.0 | 0.2 | 1.6 | 0.0 | 1.6 | 0.4 | 0.1 | 6.2 | 7.3 |
| Trial 4 | 0.4 | 0.1 | 0.5 | 0.4 | 0.5 | 3.6 | 0.6 | 0.3 | 6.3 | 6.8 |
| Trial 5 | 0.9 | 0.4 | 0.4 | 0.7 | 0.5 | 1.2 | 0.5 | 1.1 | 5.7 | 3.4 |
| Trial 6 | 0.6 | 0.4 | 0.2 | 0.2 | 3.3 | 4.1 | 0.1 | 0.1 | 8.9 | 4.4 |
| Trial 7 | 2.1 | 0.3 | 0.2 | 0.6 | 0.0 | 0.1 | 0.6 | 0.1 | 4.0 | 8.9 |
| Trial 8 | 0.2 | 0.3 | 0.6 | 0.4 | 0.7 | 0.5 | 1.3 | 0.2 | 4.1 | 11.0 |
| Subject k total | 10.0 | 5.7 | 2.9 | 4.5 | 5.3 | 13.2 | 4.5 | 2.4 | 48.5 | |

Table D.5. Scores of games initialized at 10 meters: Dev-area-mean measure

| | Subject1 | Subject2 | Subject3 | Subject4 | Subject5 | Subject6 | Subject7 | Subject8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | SD + Scuba1 | SD + Scuba2 | Trial i total | Game j total |
| Trial 1 | 481 | 318 | 59 | 82 | 316 | 85 | 262 | 94 | 1698 | 786 |
| Trial 2 | 213 | 108 | 60 | 74 | 270 | 264 | 204 | 39 | 1231 | 819 |
| Trial 3 | 196 | 196 | 118 | 178 | 345 | 371 | 71 | 72 | 1547 | 1839 |
| Trial 4 | 40 | 231 | 105 | 65 | 109 | 200 | 96 | 44 | 888 | 931 |
| Trial 5 | 84 | 135 | 176 | 101 | 242 | 168 | 212 | 192 | 1309 | 1063 |
| Trial 6 | 103 | 186 | 176 | 30 | 255 | 475 | 54 | 63 | 1342 | 819 |
| Trial 7 | 176 | 70 | 46 | 71 | 59 | 51 | 116 | 85 | 675 | 1613 |
| Trial 8 | 88 | 101 | 29 | 98 | 52 | 158 | 192 | 65 | 784 | 1605 |
| Subject k total | 1381 | 1343 | 767 | 700 | 1648 | 1774 | 1207 | 655 | 9475 | |

Table D.6. Scores of games initialized at 10 meters: Max-amp-osc measure

| | Subject1 | Subject2 | Subject3 | Subject4 | Subject5 | Subject6 | Subject7 | Subject8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | SD + Scuba1 | SD + Scuba2 | Trial i total | Game j total |
| Trial 1 | 16 | 13 | 2 | 4 | 15 | 3 | 14 | 8 | 74 | 40 |
| Trial 2 | 9 | 5 | 2 | 4 | 13 | 17 | 10 | 2 | 64 | 47 |
| Trial 3 | 9 | 10 | 7 | 9 | 18 | 18 | 5 | 4 | 80 | 81 |
| Trial 4 | 3 | 13 | 6 | 4 | 6 | 8 | 5 | 2 | 46 | 45 |
| Trial 5 | 4 | 12 | 10 | 6 | 11 | 8 | 10 | 9 | 70 | 51 |
| Trial 6 | 6 | 9 | 8 | 2 | 9 | 10 | 4 | 3 | 52 | 46 |
| Trial 7 | 10 | 4 | 2 | 3 | 4 | 2 | 8 | 4 | 37 | 70 |
| Trial 8 | 3 | 6 | 1 | 6 | 2 | 7 | 10 | 4 | 40 | 82 |
| Subject k total | 60 | 72 | 39 | 38 | 78 | 74 | 67 | 35 | 463 | |

Table D.7. Scores of games initialized at 10 meters: Caisson-RI measure

| | Subject1 | Subject2 | Subject3 | Subject4 | Subject5 | Subject6 | Subject7 | Subject8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | SD + Scuba1 | SD + Scuba2 | Trial i total | Game j total |
| Trial 1 | 11.9 | 49.1 | 0.0 | 1.0 | 0.0 | 0.0 | 4.7 | 9.2 | 75.9 | 0.0 |
| Trial 2 | 0.0 | 9.2 | 0.0 | 0.8 | 0.0 | 29.0 | 0.0 | 0.0 | 39.0 | 20.9 |
| Trial 3 | 4.1 | 13.3 | 0.0 | 25.7 | 17.2 | 0.0 | 0.0 | 0.0 | 60.3 | 35.3 |
| Trial 4 | 0.0 | 9.7 | 0.8 | 0.0 | 0.0 | 0.0 | 1.4 | 0.0 | 12.0 | 30.5 |
| Trial 5 | 0.0 | 19.9 | 0.0 | 9.9 | 0.0 | 3.4 | 4.3 | 16.5 | 53.8 | 8.4 |
| Trial 6 | 8.6 | 22.2 | 6.3 | 0.0 | 0.5 | 1.0 | 0.0 | 0.0 | 38.5 | 37.1 |
| Trial 7 | 17.2 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 9.7 | 0.0 | 27.4 | 34.0 |
| Trial 8 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 25.3 | 2.7 | 28.3 | 169.0 |
| Subject k total | 42.1 | 123.3 | 7.2 | 37.4 | 18.2 | 33.3 | 45.4 | 28.3 | 335.1 | |

Table D.8. Contrast values of effects in games initialized at 10 meters for secondary performance measures

| | Deviation of mean from 10 meters | | Deviation area from mean | | Maximum amplitude of oscillations | | Caisson disease risk index | |
|---|---|---|---|---|---|---|---|---|
| | low | high | low | high | low | high | low | high |
| Game Speed | 21 | 28 | 4375 | 5100 | 214 | 250 | 87 | 249 |
| Delay | 15 | 34 | 3487 | 5988 | 185 | 279 | 66 | 269 |
| Flow Volume | 23 | 26 | 5301 | 4174 | 243 | 221 | 78 | 258 |
| Game Speed x Delay | 22 | 27 | 4652 | 4823 | 224 | 239 | 111 | 224 |
| Game Speed x Flow Volume | 23 | 26 | 4427 | 5048 | 214 | 249 | 94 | 241 |
| Delay x Flow Volume | 24 | 24 | 5090 | 4385 | 244 | 219 | 127 | 208 |
| Game Speed x Delay x Flow Volume | 23 | 25 | 4149 | 5326 | 202 | 261 | 102 | 234 |

Table D.9. ANOVA table for secondary performance measures for games initialized at 10 meters (with log transformed data except Caisson-RI)

| | | Deviation of mean from 10 meters | | Deviation area from mean | | Maximum amplitude of oscillations | | Caisson disease risk index | |
|---|---|---|---|---|---|---|---|---|---|
| | Source of Variation | SS | P-value | SS | P-value | SS | P-value | SS | P-value |
| GameType-Total | | 14 | 0.26 | 9 | 0.00 | 7 | 0.00 | 2468 | 0.00 |
| Game Type | Game Speed | 1 | 0.36 | 1 | 0.03 | 1 | 0.04 | 410 | 0.00 |
| | Delay | 7 | 0.04 | 6 | 0.00 | 5 | 0.00 | 640 | 0.00 |
| | Flow Volume | 1 | 0.41 | 1 | 0.11 | 0 | 0.53 | 506 | 0.00 |
| | Game Speed x Delay | 2 | 0.22 | 0 | 0.98 | 0 | 0.75 | 198 | 0.03 |
| | Game Speed x Flow Volume | 0 | 0.92 | 0 | 0.23 | 0 | 0.17 | 341 | 0.00 |
| | Delay x Flow Volume | 2 | 0.24 | 0 | 0.61 | 0 | 0.50 | 101 | 0.11 |
| | Game Speed x Delay x Flow Volume | 0 | 0.87 | 1 | 0.09 | 0 | 0.15 | 272 | 0.01 |
| Subject | | 27 | 0.03 | 7 | 0.00 | 7 | 0.00 | 1087 | 0.00 |
| Practice | | 10 | 0.48 | 5 | 0.00 | 5 | 0.00 | 368 | 0.23 |
| Error | | 63 | | 8 | | 9 | | 1585 | |
| Total | | 114 | | 30 | | 27 | | 5508 | |

Table D.10. Scores of games initialized at surface: time average of amp-of-fluct measure

| | Subject9 | Subject10 | Subject11 | Subject12 | Subject13 | Subject14 | Subject15 | Subject16 | Trial i | Game |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | Scuba3 | SD3 | total | j total |
| Trial 1 | 0.78 | 0.73 | 0.38 | 0.18 | 0.57 | 0.5 | 0.46 | 0.36 | 4.0 | 2.0 |
| Trial 2 | 0.5 | 0.71 | 0.2 | 0.21 | 0.34 | 0.42 | 0.47 | 0.14 | 3.0 | 2.2 |
| Trial 3 | 0.34 | 0.7 | 0.44 | 0.3 | 0.45 | 0.13 | 0.39 | 0.42 | 3.2 | 3.3 |
| Trial 4 | 0.29 | 0.58 | 0.38 | 0.05 | 0.89 | 0.37 | 0.62 | 0.17 | 3.4 | 4.0 |
| Trial 5 | 0.15 | 0.49 | 0.43 | 0.31 | 0.48 | 0.29 | 0.43 | 0.49 | 3.1 | 2.6 |
| Trial 6 | 0.27 | 0.76 | 0.71 | 0.14 | 0.75 | 0.21 | 0.29 | 0.35 | 3.5 | 3.3 |
| Trial 7 | 0.3 | 0.39 | 0.16 | 0.25 | 0.61 | 0.11 | 0.64 | 0.56 | 3.0 | 4.0 |
| Trial 8 | 0.28 | 0.54 | 0.25 | 0.13 | 0.56 | 0.04 | 0.47 | 0.36 | 2.6 | 4.3 |
| Subject k total | 2.91 | 4.88 | 2.95 | 1.56 | 4.65 | 2.06 | 3.76 | 2.85 | 25.6 | |

Table D.11. Scores of games initialized at surface: Max-dev-10 measure

| | Subject9 | Subject10 | Subject11 | Subject12 | Subject13 | Subject14 | Subject15 | Subject16 | Trial i | Game |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | Scuba3 | SD3 | total | j total |
| Trial 1 | 10.46 | 5.82 | 3.49 | 6.72 | 5.95 | 8.8 | 4.59 | 4.85 | 50.7 | 23.3 |
| Trial 2 | 4 | 5.43 | 2.59 | 3.48 | 6.25 | 3.15 | 10.23 | 0.88 | 36.0 | 32.2 |
| Trial 3 | 2.33 | 8.81 | 5.83 | 5.86 | 4.64 | 10.04 | 6.44 | 4.2 | 48.1 | 38.3 |
| Trial 4 | 2.21 | 6.09 | 4.35 | 0.96 | 10.51 | 10.25 | 6.18 | 1.29 | 41.8 | 42.7 |
| Trial 5 | 1.46 | 2.9 | 4.32 | 3.37 | 5.86 | 5.72 | 4.67 | 4.67 | 33.0 | 29.9 |
| Trial 6 | 2.44 | 10.3 | 8.13 | 1.93 | 7.17 | 3.34 | 4.1 | 3.81 | 41.2 | 41.8 |
| Trial 7 | 2.73 | 2.22 | 1.39 | 5.84 | 8.24 | 1.7 | 6.17 | 8.61 | 36.9 | 64.8 |
| Trial 8 | 3.2 | 7.93 | 2.06 | 3.26 | 3.97 | 0.22 | 4.98 | 5.46 | 31.1 | 45.8 |
| Subject k total | 28.82 | 49.48 | 32.15 | 31.42 | 52.59 | 43.24 | 47.35 | 33.77 | 318.8 | |

Table D.12. Scores of games initialized at surface: Deviation from 10 meters in first oscillation measure

| | Subject9 | Subject10 | Subject11 | Subject12 | Subject13 | Subject14 | Subject15 | Subject16 | Trial i | Game |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | Scuba3 | SD3 | total | j total |
| Trial 1 | 3.02 | 0.23 | 1.75 | 6.62 | 2.54 | 3.48 | 1.63 | 3.5 | 22.8 | 18.3 |
| Trial 2 | 5.99 | 2.92 | 1.37 | 3.11 | 4.9 | 9.47 | 3.5 | 0.01 | 31.3 | 26.8 |
| Trial 3 | 0.57 | 0.72 | 0.44 | 5.38 | 0.62 | 9.92 | 1.6 | 0.42 | 19.7 | 27.4 |
| Trial 4 | 1.54 | 4.21 | 2.48 | 0.15 | 3.12 | 5.49 | 0.07 | 2.27 | 19.3 | 14.3 |
| Trial 5 | 0.81 | 1.23 | 6.7 | 0.69 | 0.79 | 5.65 | 4.53 | 0.84 | 21.3 | 16.7 |
| Trial 6 | 2.43 | 5.62 | 1.93 | 0.65 | 0.02 | 2.32 | 3.83 | 2.74 | 19.5 | 17.4 |
| Trial 7 | 2.28 | 5.53 | 2.76 | 2.4 | 1.86 | 1.67 | 0.67 | 1.07 | 18.2 | 22.0 |
| Trial 8 | 3.58 | 3.18 | 0.03 | 2.12 | 0.91 | 0.82 | 3.18 | 3.53 | 17.3 | 26.4 |
| Subject k total | 20.21 | 23.64 | 17.47 | 21.11 | 14.76 | 38.81 | 19.02 | 14.38 | 169.4 | |

Table D.13. Scores of games initialized at surface: Dev-mean-10mt measure

| | Subject9 | Subject10 | Subject11 | Subject12 | Subject13 | Subject14 | Subject15 | Subject16 | Trial i | Game |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | Scuba3 | SD3 | total | j total |
| Trial 1 | 0.24 | 0.54 | 0.5 | 0.18 | 0.91 | 2.34 | 0.02 | 0.16 | 4.9 | 4.2 |
| Trial 2 | 1.14 | 1.01 | 0.13 | 0.13 | 0.14 | 1.99 | 2.27 | 0.06 | 6.9 | 2.2 |
| Trial 3 | 0.26 | 0.39 | 1.4 | 0.28 | 0.43 | 0.07 | 1.89 | 0.36 | 5.1 | 6.2 |
| Trial 4 | 0.01 | 0.41 | 0.1 | 0.31 | 2.73 | 0.9 | 1.02 | 0.2 | 5.7 | 5.8 |
| Trial 5 | 0.28 | 0.46 | 1.58 | 0.6 | 0.2 | 0.17 | 0.22 | 0.52 | 4.0 | 2.7 |
| Trial 6 | 0.33 | 0.03 | 1.47 | 0.53 | 0.75 | 0.07 | 0.06 | 0.21 | 3.4 | 3.1 |
| Trial 7 | 0.22 | 0.55 | 0.58 | 2.48 | 0.4 | 0.06 | 0.5 | 1.32 | 6.1 | 8.1 |
| Trial 8 | 0.09 | 0.62 | 0.46 | 1.69 | 0.84 | 0.1 | 0.16 | 0.09 | 4.1 | 7.9 |
| Subject k total | 2.57 | 4.01 | 6.21 | 6.19 | 6.39 | 5.69 | 6.14 | 2.93 | 40.2 | |

Table D.14. Scores of games initialized at surface: Time average of dev-area-mean

| | Subject9 | Subject10 | Subject11 | Subject12 | Subject13 | Subject14 | Subject15 | Subject16 | Trial i | Game |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | Scuba3 | SD3 | total | j total |
| Trial 1 | 3.98 | 1.64 | 1.09 | 0.3 | 2.04 | 2.93 | 2.28 | 0.87 | 15.1 | 6.8 |
| Trial 2 | 2.13 | 1.87 | 0.45 | 0.37 | 0.76 | 2.65 | 2.34 | 0.32 | 10.9 | 5.2 |
| Trial 3 | 0.86 | 1.81 | 2.3 | 0.7 | 1.69 | 0.52 | 1.87 | 1.64 | 11.4 | 16.2 |
| Trial 4 | 0.63 | 2.6 | 1.29 | 0.11 | 2.98 | 1.97 | 1.52 | 0.62 | 11.7 | 15.0 |
| Trial 5 | 0.38 | 0.93 | 2.62 | 0.88 | 1.96 | 0.54 | 1.25 | 1.52 | 10.1 | 9.4 |
| Trial 6 | 0.69 | 3.89 | 2.97 | 0.62 | 2.49 | 1.23 | 0.75 | 1.44 | 14.1 | 7.8 |
| Trial 7 | 0.99 | 1.3 | 0.54 | 1.84 | 1.39 | 0.79 | 2.64 | 2.79 | 12.3 | 20.0 |
| Trial 8 | 1.28 | 2.45 | 0.57 | 0.79 | 1.17 | 0.21 | 1.3 | 1.76 | 9.5 | 14.7 |
| Subject k total | 10.94 | 16.49 | 11.82 | 5.61 | 14.47 | 10.83 | 13.95 | 10.96 | 95.1 | |

Table D.15. Scores of games initialized at surface: Max-amp-osc measure

| | Subject9 | Subject10 | Subject11 | Subject12 | Subject13 | Subject14 | Subject15 | Subject16 | Trial i | Game |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | Scuba3 | SD3 | total | j total |
| Trial 1 | 18.13 | 9.41 | 4.73 | 4.7 | 8.54 | 12.28 | 8.45 | 7.48 | 73.7 | 35.0 |
| Trial 2 | 7.83 | 8.26 | 3.84 | 2.68 | 8.23 | 9.2 | 12.43 | 1.4 | 53.9 | 39.5 |
| Trial 3 | 4.25 | 12.57 | 10.68 | 4.09 | 5.88 | 10.31 | 8.18 | 6.48 | 62.4 | 63.9 |
| Trial 4 | 4.01 | 10.3 | 6.52 | 1.33 | 11.4 | 12.04 | 6.6 | 1.9 | 54.1 | 63.0 |
| Trial 5 | 1.8 | 4.42 | 10.62 | 4.04 | 9.16 | 4.4 | 6.16 | 4.68 | 45.3 | 45.9 |
| Trial 6 | 3.19 | 15.91 | 10.28 | 3.04 | 9.09 | 5.66 | 5.33 | 5.46 | 58.0 | 51.2 |
| Trial 7 | 4.55 | 6.19 | 3.43 | 8.24 | 10.98 | 3.37 | 9.55 | 13.52 | 59.8 | 94.8 |
| Trial 8 | 6.77 | 12.95 | 3.32 | 2.9 | 5.95 | 0.97 | 6.08 | 6.88 | 45.8 | 59.7 |
| Subject k total | 50.54 | 80.01 | 53.42 | 31.02 | 69.22 | 58.24 | 62.79 | 47.81 | 453.0 | |

Table D.16. Scores of games initialized at surface: Depth range for last 20 seconds

| | Subject9 | Subject10 | Subject11 | Subject12 | Subject13 | Subject14 | Subject15 | Subject16 | Trial i | Game |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Scuba1 | Scuba2 | SD1 | SD2 | Scuba3 | SD3 | total | j total |
| Trial 1 | 9.43 | 5.94 | 3.48 | 1.23 | 4.27 | 4.73 | 8.45 | 1.57 | 39.1 | 19.6 |
| Trial 2 | 5.61 | 4.93 | 3.4 | 1.74 | 2.69 | 5.4 | 4.56 | 0.93 | 29.3 | 16.8 |
| Trial 3 | 4.25 | 12.57 | 3.52 | 4.61 | 5.02 | 0.89 | 6.2 | 3.67 | 40.7 | 45.0 |
| Trial 4 | 1.5 | 8.82 | 6.52 | 0.35 | 11.4 | 5.59 | 3.41 | 1.66 | 39.3 | 45.6 |
| Trial 5 | 1.06 | 4.6 | 6.22 | 4.04 | 5.7 | 3.79 | 6.16 | 4.73 | 36.3 | 28.9 |
| Trial 6 | 3.05 | 13.76 | 10.17 | 2.15 | 9.09 | 1.15 | 2.76 | 3.64 | 45.8 | 38.0 |
| Trial 7 | 3.37 | 1.93 | 0.79 | 2.87 | 10.98 | 0.73 | 9.55 | 8.76 | 39.0 | 52.8 |
| Trial 8 | 3.1 | 6.13 | 0.9 | 1.43 | 4.07 | 0.4 | 6.08 | 6.88 | 29.0 | 51.7 |
| Subject k total | 31.38 | 58.68 | 35.01 | 18.42 | 53.21 | 22.69 | 47.17 | 31.86 | 298.4 | |

Table D.17. Contrast values of effects in games initialized at surface for secondary performance measures

| | Deviation of Mean From 10 meters | | Time Average of Deviation Area from Mean | | Maximum Amplitude of Oscillations | | Depth Range for Last 20 seconds | |
|---|---|---|---|---|---|---|---|---|
| | low | high | low | high | low | high | low | high |
| Game Speed | 18.41 | 21.74 | 43.17 | 51.9 | 201.43 | 251.61 | 127.01 | 171.43 |
| Delay | 12.22 | 27.93 | 29.14 | 65.92 | 171.7 | 281.34 | 103.3 | 195.13 |
| Flow Volume | 21.18 | 18.97 | 52.4 | 42.67 | 239.59 | 213.45 | 146.3 | 152.13 |
| Game Speed x Delay | 17.77 | 22.38 | 48.33 | 46.73 | 223.99 | 229.05 | 157.61 | 140.82 |
| Game Speed x Flow Volume | 18.76 | 21.39 | 49.57 | 45.49 | 243.24 | 209.81 | 144.11 | 154.32 |
| Delay x Flow Volume | 19.6 | 20.55 | 49.09 | 45.98 | 249.39 | 203.65 | 152.57 | 145.86 |
| Game Speed x Delay x Flow | 21.06 | 19.08 | 49.65 | 45.42 | 244.02 | 209.02 | 155.98 | 142.45 |

Table D.18. ANOVA table for secondary performance measures for games initialized at surface (with log transformed data except max-amp-osc)

| | | Deviation of Mean From 10 meters | | Time Average of Deviation Area from Mean | | Maximum Amplitude of Oscillations | | Depth Range for Last 20 seconds | |
|---|---|---|---|---|---|---|---|---|---|
| | Source of Variation | SS | P Value | SS | P Value | SS | P Value | SS | P Value |
| Treatment-Total | | 14.6 | 0.30 | 15.4 | 0.00 | 307.6 | 0.00 | 14.2 | 0.00 |
| Treatment | Game Speed | 2.2 | 0.26 | 0.4 | 0.17 | 39.3 | 0.02 | 1.5 | 0.05 |
| | Delay | 7.4 | 0.04 | 14.1 | 0.00 | 187.8 | 0.00 | 11.7 | 0.00 |
| | Flow Rate | 0.1 | 0.77 | 0.4 | 0.17 | 10.7 | 0.23 | 0.1 | 0.65 |
| | Game Speed x Delay | 0.1 | 0.83 | 0.2 | 0.30 | 0.4 | 0.81 | 0.5 | 0.24 |
| | Game Speed x Flow Rate | 1.0 | 0.44 | 0.0 | 0.94 | 17.5 | 0.13 | 0.1 | 0.57 |
| | Delay x Flow Rate | 1.6 | 0.34 | 0.1 | 0.60 | 32.7 | 0.04 | 0.0 | 0.90 |
| | Game Speed x Delay x Flow Rate | 2.2 | 0.26 | 0.1 | 0.42 | 19.2 | 0.11 | 0.1 | 0.57 |
| Player | | 9.6 | 0.58 | 9.0 | 0.00 | 190.8 | 0.00 | 13.2 | 0.00 |
| Learning | | 3.7 | 0.94 | 1.7 | 0.38 | 74.6 | 0.201 | 1.9 | 0.65 |
| Error | | 70.5 | | 9.1 | | 302.9 | | 15.7 | |
| Total | | 98.4 | | 35.2 | | 876.0 | | 45.0 | |

# APPENDIX E: REPEATED MEASURES TABLES

Table E.1. Percentage contribution and P values: no delay (secondary measures)

| Source of Variation | | Deviation of Mean From 10 meters | Deviation Area from Mean | Maximum Amplitude of Oscillations | Caisson Disease Risk Index |
|---|---|---|---|---|---|
| | Percentage Contribution | 0,2717 | 0,4071 | 0,3781 | 0,3405 |
| Practice | P Value | 0.0415 | 0.0019 | 0.004 | 0.0097 |
| Subject | P Value | 0.0569 | 0.001 | < 0.0001 | 0.0009 |

Table E.2. Percentage contribution and P values: material delay (secondary measures)

| | | Deviation of Mean From 10 meters | Deviation Area from Mean | Maximum Amplitude of Oscillations | Caisson Disease Risk Index |
|---|---|---|---|---|---|
| | Percentage Contribution | 0,2826 | 0,2699 | 0,3360 | 0,2691 |
| Practice | P-Value | 0.0334 | 0.0429 | 0.0107 | 0.0437 |
| Subject | P-Value | 0.0863 | 0.0016 | 0.0067 | 0.0036 |

Table E.3. Percentage contribution and P values: information delay (secondary measures)

| | | Deviation of Mean From 10 meters | Deviation Area from Mean | Maximum Amplitude of | Caisson Disease Risk Index |
|---|---|---|---|---|---|
| | Percentage Contribution | 0,3619 | 0,3774 | 0,3129 | 0,2751 |
| Practice | P-Value | 0.0059 | 0.004 | 0.0178 | 0.0388 |
| Subject | P-Value | 0.1658 | 0.2495 | 0.0784 | 0.1307 |

Table E.4. Percentage contribution and P values: both-delays (secondary measures)

| | Source of Variation | | Deviation of Mean From 10 meters | Deviation Area from Mean | Maximum Amplitude of Oscillations | Caisson Disease Risk Index |
|---|---|---|---|---|---|---|
| Original Data | | Percentage Contribution | 0,4097 | 0,5066 | 0,4398 | 0,4174 |
| | Practice | P Value | 0.0161 | 0.0022 | 0.0092 | 0.014 |
| | Subject | P Value | 0.8835 | 0.1206 | 0.0981 | < 0.0001 |
| Outlier Deleted | | Percentage Contribution | 0,4569 | 0,4747 | 0,4260 | 0,4491 |
| | Practice | P Value | 0.0084 | 0.0059 | 0.015 | 0.0098 |
| | Subject | P Value | 0.2669 | 0.1072 | 0.1098 | < 0.0001 |
| Regression applied for outlier | | Percentage Contribution | 0.4501 | 0.4873 | 0.4375 | 0.4338 |
| | Practice | P Value | 0.0075 | 0.0035 | 0.0096 | 0.0103 |
| | Subject | P Value | 0.1523 | 0.0877 | 0.0942 | < 0.0001 |

Table E.5. Percentage contribution and P values: with pause option (secondary measures)

| Source of Variation | | Deviation of Mean From 10 meters | Deviation Area from Mean | Maximum Amplitude of Oscillations | Caisson Disease Risk Index |
|---|---|---|---|---|---|
| | Percentage Contribution | 0,1671 | 0,2923 | 0,2583 | 0,1510 |
| Practice | P Value | 0.3313 | 0.0541 | 0.0944 | 0.0754 |
| Subject | P Value | 0.007 | < 0.0001 | 0.0007 | 0.0033 |

Table E.6. Percentage contribution and P values: scuba divers (secondary measures)

| Source of Variation | | Deviation of Mean From 10 meters | Deviation Area from Mean | Maximum Amplitude of Oscillations | Caisson Disease Risk Index |
|---|---|---|---|---|---|
| | Percentage Contribution | 0.42 | 0.33 | 0.21 | 0.24 |
| Practice | P Value | 0.02 | 0.07 | 0.32 | 0.22 |
| Player | P Value | 0.03 | < 0.0001 | 0 | 0.01 |

Table E.7. Levene's Test of equality of error variances: no delay and material delay

| | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Trial1 | 0,36 | 0,06 | 0,39 | 0,02 | 0,35 | 0,27 | 0,28 | 0,18 |
| Trial2 | 0,52 | 0,39 | 0,71 | 1,00 | 0,53 | 0,49 | 0,75 | 0,73 |
| Trial3 | 0,29 | 0,28 | 0,82 | 0,00 | 0,01 | 0,50 | 0,78 | 0,14 |
| Trial4 | 0,05 | 0,20 | 0,51 | 0,00 | 0,89 | 0,05 | 0,06 | 0,02 |
| Trial5 | 0,30 | 0,52 | 0,84 | 0,01 | 0,96 | 0,23 | 0,64 | 0,15 |
| Trial6 | 0,90 | 0,07 | 0,83 | 0,05 | 0,97 | 0,87 | 0,33 | 0,02 |

Table E.8. Box’s M Test for equality of covariance matrices:no delay and material delay

| | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Box's M | 80 | 43 | 68 | ----- | 94 | 66 | 69 | ----- |
| F | 1,98 | 1,06 | 1,67 | ----- | 2,31 | 1,62 | 1,69 | ----- |
| Significance | 0,006 | 0,390 | 0,031 | ----- | 0,001 | 0,039 | 0,027 | ----- |

Table E.9. Mauchly's Test of sphericity: no delay and material delay

| | | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Significance | | 0.1 | 0.27 | 0.76 | 0.24 | 0.15 | 0.21 | 0.42 | 0.07 |
| | Greenhouse-Geisser | 0.64 | 0.61 | 0.8 | 0.65 | 0.65 | 0.64 | 0.76 | 0.62 |
| | Huynh-Feldt | 0.9 | 0.86 | 1 | 0.93 | 0.93 | 0.91 | 1 | 0.88 |
| Epsilon | Lower-bound | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

Table E.10. ANOVA Table for practice and material delay effects (primary measures)

| | | Dev-10-mt | | Amp-of-fluct | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0,00 | 0,28 | 0,00 | 0,46 | 0,00 | 0,28 | 0,00 | 0,25 |
| | Greenhouse-Geisser | 0,00 | 0,28 | 0,00 | 0,46 | 0,00 | 0,28 | 0,01 | 0,25 |
| | Huynh-Feldt | 0,00 | 0,28 | 0,00 | 0,46 | 0,00 | 0,28 | 0,00 | 0,25 |
| | Lower-bound | 0,03 | 0,28 | 0,00 | 0,46 | 0,04 | 0,28 | 0,05 | 0,25 |
| practice * Material | Sphericity Assumed | 0,15 | 0,11 | 0,50 | 0,06 | 0,50 | 0,06 | 0,02 | 0,17 |
| | Greenhouse-Geisser | 0,19 | 0,11 | 0,46 | 0,06 | 0,49 | 0,06 | 0,05 | 0,17 |
| | Huynh-Feldt | 0,16 | 0,11 | 0,49 | 0,06 | 0,50 | 0,06 | 0,03 | 0,17 |
| | Lower-bound | 0,22 | 0,11 | 0,37 | 0,06 | 0,37 | 0,06 | 0,12 | 0,17 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0,00 | 0,92 | 0,00 | 0,92 | 0,00 | 0,91 | 0,00 | 0,96 |
| Material | | 0,01 | 0,44 | 0,03 | 0,31 | 0,02 | 0,34 | 0,00 | 0,52 |

Table E. 11. ANOVA Table for practice and material delay effects (secondary measures)

| | | Deviation of Mean From 10 meters | | Deviation Area from Mean | | Maximum Amplitude of Oscillations | | Caisson Disease Risk Index | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0.00 | 0.26 | 0.00 | 0.26 | 0.00 | 0.28 | 0.00 | 0.28 |
| | Greenhouse-Geisser | 0.00 | 0.26 | 0.00 | 0.26 | 0.00 | 0.28 | 0.00 | 0.28 |
| | Huynh-Feldt | 0.00 | 0.26 | 0.00 | 0.26 | 0.00 | 0.28 | 0.00 | 0.28 |
| | Lower-bound | 0.04 | 0.26 | 0.04 | 0.26 | 0.04 | 0.28 | 0.04 | 0.28 |
| practice * Material Delay | Sphericity Assumed | 0.85 | 0.03 | 0.09 | 0.13 | 0.05 | 0.14 | 0.68 | 0.04 |
| | Greenhouse-Geisser | 0.77 | 0.03 | 0.12 | 0.13 | 0.08 | 0.14 | 0.60 | 0.04 |
| | Huynh-Feldt | 0.83 | 0.03 | 0.10 | 0.13 | 0.05 | 0.14 | 0.66 | 0.04 |
| | Lower-bound | 0.54 | 0.03 | 0.18 | 0.13 | 0.15 | 0.14 | 0.44 | 0.04 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0.00 | 0.84 | 0.00 | 0.92 | 0.00 | 0.91 | 0.00 | 0.63 |
| Material | | 0.39 | 0.05 | 0.00 | 0.46 | 0.01 | 0.43 | 0.08 | 0.21 |

Table E.12. Levene's Test of equality of error variances: no delay and information delay

| | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Trial1 | 0.78 | 0.88 | 0.01 | 0.02 | 0.09 | 0.2 | 0.28 | 0.7 |
| Trial2 | 0.36 | 0.13 | 0.99 | 0 | 0.57 | 0.51 | 0.86 | 0.16 |
| Trial3 | 0.02 | 0.49 | 0.62 | 0 | 0.1 | 0.04 | 0.89 | 0.28 |
| Trial4 | 0.07 | 0.73 | 0.14 | 0 | 0.08 | 0.02 | 0.05 | 0.35 |
| Trial5 | 0.02 | 0.47 | 0.39 | 0.04 | 0.44 | 0.02 | 0.06 | 0.06 |
| Trial6 | 0.09 | 0.17 | 0.06 | 0.06 | 0.28 | 0.13 | 0.19 | 0.09 |

Table E.13. Box's M Test of equality of covariance matrices: no delay-information delay

| | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Box's M | 76 | 44 | 66 | 114 | 79 | 57 | 74 | ----- |
| F | 1,86 | 1,08 | 1,62 | 2,82 | 1,95 | 1,40 | 1,81 | ----- |
| Significance | 0,011 | 0,359 | 0,040 | 0,000 | 0,007 | 0,111 | 0,014 | ----- |

Table E.14. Mauchly's Test of sphericity: no delay and information delay

| | | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Significance | | 0,01 | 0,04 | 0,07 | 0,20 | 0,27 | 0,01 | 0,00 | 0,00 |
| Epsilon | Greenhouse-Geisser | 0,50 | 0,53 | 0,64 | 0,64 | 0,67 | 0,52 | 0,51 | 0,41 |
| | Huynh-Feldt | 0,66 | 0,72 | 0,91 | 0,91 | 0,97 | 0,70 | 0,68 | 0,51 |
| | Lower-bound | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 |

Table E.15. ANOVA Table for practice and information delay effects (primary measures)

| | | Dev-10-mt | | Amp-of-fluct | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0,00 | 0,37 | 0,00 | 0,47 | 0,00 | 0,33 | 0,00 | 0,26 |
| | Greenhouse-Geisser | 0,00 | 0,37 | 0,00 | 0,47 | 0,00 | 0,33 | 0,00 | 0,26 |
| | Huynh-Feldt | 0,00 | 0,37 | 0,00 | 0,47 | 0,00 | 0,33 | 0,00 | 0,26 |
| | Lower-bound | 0,01 | 0,37 | 0,00 | 0,47 | 0,02 | 0,33 | 0,05 | 0,26 |
| practice * Information | Sphericity Assumed | 0,30 | 0,08 | 0,87 | 0,03 | 0,80 | 0,03 | 0,03 | 0,16 |
| | Greenhouse-Geisser | 0,31 | 0,08 | 0,75 | 0,03 | 0,71 | 0,03 | 0,06 | 0,16 |
| | Huynh-Feldt | 0,31 | 0,08 | 0,81 | 0,03 | 0,78 | 0,03 | 0,04 | 0,16 |
| | Lower-bound | 0,28 | 0,08 | 0,55 | 0,03 | 0,50 | 0,03 | 0,13 | 0,16 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0,00 | 0,95 | 0,00 | 0,93 | 0,00 | 0,91 | 0,00 | 0,97 |
| Information | | 0,00 | 0,68 | 0,02 | 0,33 | 0,00 | 0,46 | 0,00 | 0,54 |

Table E.16. ANOVA Table for practice and information delay effect (secondary measures)

| | | Deviation of Mean From 10 meters | | Deviation Area from Mean | | Maximum Amplitude of Oscillations | | Caisson Disease Risk Index | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0.00 | 0.28 | 0.00 | 0.36 | 0.00 | 0.32 | 0.00 | 0.29 |
| | Greenhouse-Geisser | 0.00 | 0.28 | 0.00 | 0.36 | 0.00 | 0.32 | 0.01 | 0.29 |
| | Huynh-Feldt | 0.00 | 0.28 | 0.00 | 0.36 | 0.00 | 0.32 | 0.00 | 0.29 |
| | Lower-bound | 0.03 | 0.28 | 0.01 | 0.36 | 0.02 | 0.32 | 0.03 | 0.29 |
| practice * Information Delay | Sphericity Assumed | 0.13 | 0.11 | 0.56 | 0.05 | 0.87 | 0.03 | 0.96 | 0.01 |
| | Greenhouse-Geisser | 0.16 | 0.11 | 0.49 | 0.05 | 0.74 | 0.03 | 0.83 | 0.01 |
| | Huynh-Feldt | 0.13 | 0.11 | 0.52 | 0.05 | 0.80 | 0.03 | 0.87 | 0.01 |
| | Lower-bound | 0.20 | 0.11 | 0.39 | 0.05 | 0.55 | 0.03 | 0.67 | 0.01 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0.00 | 0.87 | 0.00 | 0.94 | 0.00 | 0.92 | 0.00 | 0.69 |
| Information | | 0.01 | 0.39 | 0.00 | 0.66 | 0.00 | 0.48 | 0.03 | 0.29 |

Table E.17. Box's M Test of equality of covariance matrix: material-information-no delay

| | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Box's M | 119 | 75 | 97 | 114 | 128 | 98 | 114 | 48 |
| F | 1,60 | 1,01 | 1,30 | 2,82 | 1,71 | 1,32 | 1,54 | 1,18 |
| Significance | 0,009 | 0,454 | 0,095 | 0,000 | 0,003 | 0,086 | 0,016 | 0,262 |

Table E.18. Levene's Test of equality of error variances: material-information-no delay

| | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Trial1 | 0,69 | 0,07 | 0,04 | 0,00 | 0,29 | 0,41 | 0,38 | 0,14 |
| Trial2 | 0,63 | 0,25 | 0,87 | 0,10 | 0,80 | 0,74 | 0,87 | 0,24 |
| Trial3 | 0,07 | 0,54 | 0,71 | 0,00 | 0,13 | 0,11 | 0,96 | 0,25 |
| Trial4 | 0,07 | 0,34 | 0,44 | 0,00 | 0,07 | 0,07 | 0,11 | 0,02 |
| Trial5 | 0,08 | 0,74 | 0,61 | 0,01 | 0,69 | 0,06 | 0,07 | 0,11 |
| Trial6 | 0,09 | 0,25 | 0,03 | 0,05 | 0,36 | 0,15 | 0,30 | 0,13 |

Table E.19. Mauchly's Test of sphericity: material-information-no delay

| | | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Significance | | 0,01 | 0,10 | 0,40 | 0,04 | 0,28 | 0,03 | 0,02 | 0,00 |
| Epsilon | Greenhouse-Geisser | 0,66 | 0,67 | 0,80 | 0,68 | 0,75 | 0,69 | 0,67 | 0,58 |
| | Huynh-Feldt | 0,87 | 0,89 | 1,00 | 0,90 | 1,00 | 0,92 | 0,89 | 0,75 |
| | Lower-bound | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 |

Table E.20. ANOVA Table for practice and delay type effects (primary measures)

| | | Dev-10-mt | | Amp-of-fluct | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0,00 | 0,31 | 0,00 | 0,45 | 0,00 | 0,30 | 0,00 | 0,21 |
| | Greenhouse-Geisser | 0,00 | 0,31 | 0,00 | 0,45 | 0,00 | 0,30 | 0,00 | 0,21 |
| | Huynh-Feldt | 0,00 | 0,31 | 0,00 | 0,45 | 0,00 | 0,30 | 0,00 | 0,21 |
| | Lower-bound | 0,01 | 0,31 | 0,00 | 0,45 | 0,01 | 0,30 | 0,03 | 0,21 |
| practice * Delay Type | Sphericity Assumed | 0,12 | 0,13 | 0,76 | 0,06 | 0,83 | 0,05 | 0,01 | 0,19 |
| | Greenhouse-Geisser | 0,15 | 0,13 | 0,70 | 0,06 | 0,79 | 0,05 | 0,03 | 0,19 |
| | Huynh-Feldt | 0,13 | 0,13 | 0,75 | 0,06 | 0,83 | 0,05 | 0,02 | 0,19 |
| | Lower-bound | 0,22 | 0,13 | 0,53 | 0,06 | 0,57 | 0,05 | 0,11 | 0,19 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0,00 | 0,94 | 0,00 | 0,94 | 0,00 | 0,93 | 0,00 | 0,98 |
| Delay Type | | 0,00 | 0,55 | 0,02 | 0,31 | 0,00 | 0,41 | 0,00 | 0,58 |

Table E.21. ANOVA Table for practice and delay type effects (secondary measures)

| | | Deviation of Mean From 10 meters | | Deviation Area from Mean | | Maximum Amplitude of Oscillations | | Caisson Disease Risk Index | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0.00 | 0.28 | 0.00 | 0.29 | 0.00 | 0.27 | 0.00 | 0.26 |
| | Greenhouse-Geisser | 0.00 | 0.28 | 0.00 | 0.29 | 0.00 | 0.27 | 0.00 | 0.26 |
| | Huynh-Feldt | 0.00 | 0.28 | 0.00 | 0.29 | 0.00 | 0.27 | 0.00 | 0.26 |
| | Lower-bound | 0.01 | 0.28 | 0.01 | 0.29 | 0.01 | 0.27 | 0.01 | 0.26 |
| practice * Delay Type | Sphericity Assumed | 0.45 | 0.09 | 0.13 | 0.13 | 0.23 | 0.11 | 0.84 | 0.05 |
| | Greenhouse-Geisser | 0.45 | 0.09 | 0.16 | 0.13 | 0.26 | 0.11 | 0.75 | 0.05 |
| | Huynh-Feldt | 0.45 | 0.09 | 0.14 | 0.13 | 0.24 | 0.11 | 0.80 | 0.05 |
| | Lower-bound | 0.39 | 0.09 | 0.23 | 0.13 | 0.29 | 0.11 | 0.58 | 0.05 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0.00 | 0.86 | 0.00 | 0.94 | 0.00 | 0.93 | 0.00 | 0.72 |
| Delay Type | | 0.02 | 0.32 | 0.00 | 0.54 | 0.00 | 0.44 | 0.07 | 0.23 |

Table E.22. Box's M Test of equality of covariance matrices for no delay, material delay, information delay and both-delays comparison

| | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Box's M | 119 | 75 | 97 | 114 | 128 | 98 | 114 | 48 |
| F | 1,60 | 1,01 | 1,30 | 2,82 | 1,71 | 1,32 | 1,54 | 1,18 |
| Significance | 0,009 | 0,454 | 0,095 | 0,000 | 0,003 | 0,086 | 0,016 | 0,262 |

Table E.23. Levene's Test of equality of error variances: no delay – both delays

| | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Trial1 | 0,38 | 0,03 | 0,02 | 0,00 | 0,52 | 0,17 | 0,20 | 0,08 |
| Trial2 | 0,68 | 0,21 | 0,09 | 0,05 | 0,44 | 0,77 | 0,94 | 0,00 |
| Trial3 | 0,02 | 0,34 | 0,73 | 0,00 | 0,26 | 0,00 | 0,92 | 0,05 |
| Trial4 | 0,08 | 0,52 | 0,57 | 0,00 | 0,10 | 0,03 | 0,18 | 0,03 |
| Trial5 | 0,13 | 0,10 | 0,73 | 0,00 | 0,32 | 0,10 | 0,11 | 0,06 |
| Trial6 | 0,08 | 0,35 | 0,04 | 0,00 | 0,43 | 0,08 | 0,33 | 0,16 |

Table E.24. Mauchly's Test of sphericity: no delay – both delays

| | | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Significance | | 0,04 | 0,07 | 0,48 | 0,01 | 0,43 | 0,16 | 0,01 | 0,00 |
| Epsilon | Greenhouse-Geisser | 0,75 | 0,69 | 0,83 | 0,68 | 0,80 | 0,78 | 0,71 | 0,64 |
| | Huynh-Feldt | 0,99 | 0,90 | 1,00 | 0,89 | 1,00 | 1,00 | 0,92 | 0,83 |
| | Lower-bound | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 |

Table E.25. ANOVA Table for practice, material and information delay: (primary measures)

| | | Dev-10-mt | | Amp-of-fluct | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0,00 | 0,37 | 0,00 | 0,46 | 0,00 | 0,36 | 0,00 | 0,16 |
| | Greenhouse-Geisser | 0,00 | 0,37 | 0,00 | 0,46 | 0,00 | 0,36 | 0,00 | 0,16 |
| | Huynh-Feldt | 0,00 | 0,37 | 0,00 | 0,46 | 0,00 | 0,36 | 0,00 | 0,16 |
| | Lower-bound | 0,00 | 0,37 | 0,00 | 0,46 | 0,00 | 0,36 | 0,04 | 0,16 |
| practice * Information | Sphericity Assumed | 0,07 | 0,07 | 0,93 | 0,01 | 0,54 | 0,03 | 0,04 | 0,09 |
| | Greenhouse-Geisser | 0,09 | 0,07 | 0,87 | 0,01 | 0,52 | 0,03 | 0,06 | 0,09 |
| | Huynh-Feldt | 0,07 | 0,07 | 0,91 | 0,01 | 0,54 | 0,03 | 0,05 | 0,09 |
| | Lower-bound | 0,16 | 0,07 | 0,60 | 0,01 | 0,38 | 0,03 | 0,13 | 0,09 |
| practice * Material | Sphericity Assumed | 0,04 | 0,09 | 0,16 | 0,06 | 0,23 | 0,05 | 0,02 | 0,10 |
| | Greenhouse-Geisser | 0,06 | 0,09 | 0,19 | 0,06 | 0,24 | 0,05 | 0,04 | 0,10 |
| | Huynh-Feldt | 0,04 | 0,09 | 0,17 | 0,06 | 0,23 | 0,05 | 0,03 | 0,10 |
| | Lower-bound | 0,13 | 0,09 | 0,22 | 0,06 | 0,25 | 0,05 | 0,11 | 0,10 |
| practice * Information * Material | Sphericity Assumed | 0,42 | 0,04 | 0,93 | 0,01 | 0,81 | 0,02 | 0,13 | 0,06 |
| | Greenhouse-Geisser | 0,41 | 0,04 | 0,88 | 0,01 | 0,77 | 0,02 | 0,16 | 0,06 |
| | Huynh-Feldt | 0,42 | 0,04 | 0,92 | 0,01 | 0,81 | 0,02 | 0,14 | 0,06 |
| | Lower-bound | 0,33 | 0,04 | 0,61 | 0,01 | 0,50 | 0,02 | 0,20 | 0,06 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0,00 | 0,95 | 0,00 | 0,93 | 0,00 | 0,95 | 0,00 | 0,98 |
| Information | | 0,00 | 0,56 | 0,02 | 0,20 | 0,00 | 0,39 | 0,00 | 0,38 |
| Material | | 0,00 | 0,36 | 0,01 | 0,21 | 0,01 | 0,23 | 0,00 | 0,38 |
| Information * Material | | 0,46 | 0,02 | 0,63 | 0,01 | 0,28 | 0,05 | 0,01 | 0,25 |

Table E. 26. ANOVA Table for practice, material and information delay: secondary measures

| | | Deviation of Mean From 10 meters | | Deviation Area from Mean | | Maximum Amplitude of Oscillations | | Caisson Disease Risk Index | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0.00 | 0.33 | 0.00 | 0.33 | 0.00 | 0.30 | 0.00 | 0.29 |
| | Greenhouse-Geisser | 0.00 | 0.33 | 0.00 | 0.33 | 0.00 | 0.30 | 0.00 | 0.29 |
| | Huynh-Feldt | 0.00 | 0.33 | 0.00 | 0.33 | 0.00 | 0.30 | 0.00 | 0.29 |
| | Lower-bound | 0.00 | 0.33 | 0.00 | 0.33 | 0.00 | 0.30 | 0.00 | 0.29 |
| practice * Information Delay | Sphericity Assumed | 0.16 | 0.06 | 0.16 | 0.06 | 0.64 | 0.03 | 0.77 | 0.02 |
| | Greenhouse-Geisser | 0.17 | 0.06 | 0.18 | 0.06 | 0.59 | 0.03 | 0.69 | 0.02 |
| | Huynh-Feldt | 0.16 | 0.06 | 0.16 | 0.06 | 0.63 | 0.03 | 0.74 | 0.02 |
| | Lower-bound | 0.21 | 0.06 | 0.21 | 0.06 | 0.42 | 0.03 | 0.48 | 0.02 |
| practice * Material Delay | Sphericity Assumed | 0.74 | 0.02 | 0.01 | 0.11 | 0.03 | 0.09 | 0.16 | 0.06 |
| | Greenhouse-Geisser | 0.70 | 0.02 | 0.02 | 0.11 | 0.04 | 0.09 | 0.19 | 0.06 |
| | Huynh-Feldt | 0.74 | 0.02 | 0.01 | 0.11 | 0.03 | 0.09 | 0.18 | 0.06 |
| | Lower-bound | 0.46 | 0.02 | 0.09 | 0.11 | 0.11 | 0.09 | 0.22 | 0.06 |
| practice * Information * Material | Sphericity Assumed | 0.55 | 0.03 | 0.66 | 0.02 | 0.84 | 0.02 | 0.67 | 0.02 |
| | Greenhouse-Geisser | 0.52 | 0.03 | 0.62 | 0.02 | 0.78 | 0.02 | 0.60 | 0.02 |
| | Huynh-Feldt | 0.55 | 0.03 | 0.66 | 0.02 | 0.82 | 0.02 | 0.64 | 0.02 |
| | Lower-bound | 0.38 | 0.03 | 0.43 | 0.02 | 0.53 | 0.02 | 0.43 | 0.02 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0.00 | 0.88 | 0.00 | 0.95 | 0.00 | 0.95 | 0.00 | 0.68 |
| Information | | 0.00 | 0.42 | 0.00 | 0.53 | 0.00 | 0.35 | 0.03 | 0.18 |
| Material | | 0.16 | 0.07 | 0.00 | 0.35 | 0.00 | 0.31 | 0.05 | 0.14 |
| Information * Material | | 0.69 | 0.01 | 0.33 | 0.04 | 0.21 | 0.06 | 0.96 | 0.00 |

Table E.27. Levene's Test of equality of error variances: with and without pause option

| | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Trial1 | 0,04 | 0,42 | 0,04 | 0,12 | 0,23 | 0,01 | 0,12 | 0,70 |
| Trial2 | 0,44 | 0,52 | 0,09 | 0,30 | 0,36 | 0,39 | 0,67 | 0,36 |
| Trial3 | 0,06 | 0,02 | 0,32 | 0,05 | 0,30 | 0,09 | 0,25 | 0,39 |
| Trial4 | 0,45 | 0,99 | 0,39 | 0,15 | 0,03 | 0,84 | 0,46 | 0,56 |
| Trial5 | 0,71 | 0,32 | 0,88 | 0,50 | 0,13 | 0,49 | 0,70 | 0,69 |
| Trial6 | 0,02 | 0,87 | 0,12 | 0,29 | 0,17 | 0,00 | 0,02 | 0,55 |

Table E.28. Mauchly's Test of sphericity: with and without pause option

| | | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Significance | | 0,28 | 0,14 | 0,26 | 0,00 | 0,70 | 0,13 | 0,10 | 0,66 |
| Epsilon | Greenhouse-Geisser | 0,59 | 0,54 | 0,67 | 0,61 | 0,78 | 0,58 | 0,59 | 0,66 |
| | Huynh-Feldt | 0,90 | 0,80 | 1,00 | 0,95 | 1,00 | 0,88 | 0,89 | 1,00 |
| | Lower-bound | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 |

Table E.29. ANOVA Table for pause and practice effects (primary measures)

| | | Dev-10-mt | | Amp-of-fluct | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0,00 | 0,37 | 0,00 | 0,35 | 0,00 | 0,40 | 0,39 | 0,09 |
| | Greenhouse-Geisser | 0,00 | 0,37 | 0,00 | 0,35 | 0,00 | 0,40 | 0,38 | 0,09 |
| | Huynh-Feldt | 0,00 | 0,37 | 0,00 | 0,35 | 0,00 | 0,40 | 0,39 | 0,09 |
| | Lower-bound | 0,03 | 0,37 | 0,03 | 0,35 | 0,02 | 0,40 | 0,32 | 0,09 |
| practice * Pause | Sphericity Assumed | 0,43 | 0,08 | 0,38 | 0,09 | 0,23 | 0,11 | 0,20 | 0,12 |
| | Greenhouse-Geisser | 0,41 | 0,08 | 0,37 | 0,09 | 0,25 | 0,11 | 0,23 | 0,12 |
| | Huynh-Feldt | 0,42 | 0,08 | 0,38 | 0,09 | 0,23 | 0,11 | 0,20 | 0,12 |
| | Lower-bound | 0,34 | 0,08 | 0,32 | 0,09 | 0,26 | 0,11 | 0,24 | 0,12 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0,00 | 0,89 | 0,00 | 0,93 | 0,00 | 0,96 | 0,00 | 1,00 |
| Pause | | 0,68 | 0,02 | 0,85 | 0,00 | 0,70 | 0,01 | 0,57 | 0,03 |

Table E.30. ANOVA Table for pause and practice effects (secondary measures)

| | | Deviation of Mean From 10 meters | | Deviation Area from Mean | | Maximum Amplitude of Oscillations | | Caisson Disease Risk Index | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0.01 | 0.25 | 0.00 | 0.36 | 0.00 | 0.30 | 0.00 | 0.30 |
| | Greenhouse-Geisser | 0.01 | 0.25 | 0.00 | 0.36 | 0.01 | 0.30 | 0.01 | 0.30 |
| | Huynh-Feldt | 0.01 | 0.25 | 0.00 | 0.36 | 0.00 | 0.30 | 0.00 | 0.30 |
| | Lower-bound | 0.08 | 0.25 | 0.03 | 0.36 | 0.05 | 0.30 | 0.05 | 0.30 |
| practice * Pause | Sphericity Assumed | 0.19 | 0.12 | 0.68 | 0.05 | 0.51 | 0.07 | 0.51 | 0.07 |
| | Greenhouse-Geisser | 0.20 | 0.12 | 0.59 | 0.05 | 0.47 | 0.07 | 0.48 | 0.07 |
| | Huynh-Feldt | 0.19 | 0.12 | 0.66 | 0.05 | 0.50 | 0.07 | 0.51 | 0.07 |
| | Lower-bound | 0.24 | 0.12 | 0.44 | 0.05 | 0.37 | 0.07 | 0.37 | 0.07 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0.00 | 0.86 | 0.00 | 0.89 | 0.00 | 0.94 | 0.00 | 0.73 |
| Pause | | 0.99 | 0.00 | 0.62 | 0.02 | 0.49 | 0.04 | 0.87 | 0.00 |

Table E.31. Levene's Test of equality of error variances: scuba and non scuba divers

| | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Trial1 | 0,01 | 0,54 | 0,05 | 0,96 | 0,13 | 0,01 | 0,10 | 0,18 |
| Trial2 | 0,44 | 0,42 | 0,17 | 0,00 | 0,31 | 0,45 | 0,11 | 0,07 |
| Trial3 | 0,45 | 0,86 | 0,64 | 0,72 | 0,29 | 0,52 | 0,84 | 0,51 |
| Trial4 | 0,07 | 0,06 | 0,29 | 0,02 | 0,23 | 0,03 | 0,09 | 0,62 |
| Trial5 | 0,65 | 0,42 | 0,47 | 0,55 | 0,19 | 0,90 | 0,88 | 0,38 |
| Trial6 | 0,95 | 0,21 | 0,79 | 0,23 | 0,42 | 0,91 | 0,70 | 0,31 |

Table E.32. Mauchly's Test of sphericity: scuba and non scuba divers

| | | Performance Measure | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Significance | | 0 | 0 | 0.01 | 0.8 | 0.04 | 0 | 0.01 | 0 |
| Epsilon | Greenhouse-Geisser | 0.4 | 0.43 | 0.52 | 0.71 | 0.56 | 0.41 | 0.5 | 0.31 |
| | Huynh-Feldt | 0.53 | 0.59 | 0.76 | 1 | 0.83 | 0.55 | 0.71 | 0.38 |
| | Lower-bound | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

Table E.33. ANOVA Table for scuba diving experience (primary measures)

| | | Deviation area from 10 meters | | Total Amplitude of Fluctuations | | Maximum Deviation from 10 meters | | ±2 Settling Time | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0,00 | 0,35 | 0,00 | 0,44 | 0,03 | 0,19 | 0,00 | 0,28 |
| | Greenhouse-Geisser | 0,01 | 0,35 | 0,00 | 0,44 | 0,08 | 0,19 | 0,01 | 0,28 |
| | Huynh-Feldt | 0,00 | 0,35 | 0,00 | 0,44 | 0,05 | 0,19 | 0,00 | 0,28 |
| | Lower-bound | 0,03 | 0,35 | 0,01 | 0,44 | 0,13 | 0,19 | 0,06 | 0,28 |
| practice * Scuba | Sphericity Assumed | 0,62 | 0,06 | 0,60 | 0,06 | 0,37 | 0,09 | 0,52 | 0,07 |
| | Greenhouse-Geisser | 0,50 | 0,06 | 0,50 | 0,06 | 0,35 | 0,09 | 0,49 | 0,07 |
| | Huynh-Feldt | 0,54 | 0,06 | 0,54 | 0,06 | 0,36 | 0,09 | 0,52 | 0,07 |
| | Lower-bound | 0,42 | 0,06 | 0,41 | 0,06 | 0,31 | 0,09 | 0,38 | 0,07 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0,00 | 0,86 | 0,00 | 0,83 | 0,00 | 0,80 | 0,00 | 0,80 |
| Scuba | | 0,32 | 0,09 | 0,65 | 0,02 | 0,34 | 0,08 | 0,49 | 0,05 |

Table E.34. ANOVA Table for scuba diving experience (secondary measures)

| | | Deviation of Mean From 10 meters | | Deviation Area from Mean | | Maximum Amplitude of Oscillations | | Caisson Disease Risk Index | |
|---|---|---|---|---|---|---|---|---|---|
| Source | | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared | Sig. | Partial Eta Squared |
| Tests of Within-Subjects Effects | | | | | | | | | |
| practice | Sphericity Assumed | 0.01 | 0.24 | 0.00 | 0.33 | 0.01 | 0.24 | 0.01 | 0.23 |
| | Greenhouse-Geisser | 0.03 | 0.24 | 0.01 | 0.33 | 0.04 | 0.24 | 0.08 | 0.23 |
| | Huynh-Feldt | 0.01 | 0.24 | 0.01 | 0.33 | 0.02 | 0.24 | 0.06 | 0.23 |
| | Lower-bound | 0.09 | 0.24 | 0.04 | 0.33 | 0.09 | 0.24 | 0.10 | 0.23 |
| practice * Scuba Diving Experience | Sphericity Assumed | 0.50 | 0.07 | 0.53 | 0.07 | 0.34 | 0.09 | 0.39 | 0.09 |
| | Greenhouse-Geisser | 0.46 | 0.07 | 0.45 | 0.07 | 0.34 | 0.09 | 0.35 | 0.09 |
| | Huynh-Feldt | 0.49 | 0.07 | 0.48 | 0.07 | 0.34 | 0.09 | 0.36 | 0.09 |
| | Lower-bound | 0.37 | 0.07 | 0.38 | 0.07 | 0.31 | 0.09 | 0.32 | 0.09 |
| Tests of Between-Subjects Effects | | | | | | | | | |
| Intercept | | 0.00 | 0.81 | 0.00 | 0.84 | 0.00 | 0.81 | 0.04 | 0.34 |
| Scuba | | 0.08 | 0.25 | 0.41 | 0.06 | 0.39 | 0.07 | 0.51 | 0.04 |

Table E.35. Dev-10-mt and amp-of-fluct scores obtained by Subject 17-59

| | | Deviation Area from 10 meters | | | | | | Total Amplitude of Fluctuations | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No delay | Subject 17 | 86 | 76 | 69 | 83 | 126 | 82 | 39 | 36 | 13 | 23 | 14 | 21 |
| | Subject 18 | 238 | 195 | 131 | 84 | 150 | 69 | 65 | 65 | 53 | 38 | 49 | 40 |
| | Subject 19 | 72 | 88 | 61 | 72 | 59 | 68 | 33 | 17 | 18 | 30 | 21 | 30 |
| | Subject 20 | 216 | 137 | 40 | 50 | 37 | 52 | 43 | 31 | 16 | 19 | 18 | 18 |
| | Subject 21 | 204 | 121 | 71 | 140 | 93 | 179 | 58 | 47 | 39 | 53 | 34 | 22 |
| | Subject 22 | 84 | 89 | 47 | 56 | 33 | 67 | 33 | 25 | 17 | 22 | 13 | 19 |
| | Subject 23 | 296 | 255 | 99 | 88 | 77 | 56 | 83 | 69 | 33 | 30 | 29 | 14 |
| | Subject 24 | 44 | 73 | 52 | 71 | 78 | 55 | 16 | 13 | 10 | 15 | 22 | 17 |
| Material Delay | Subject 25 | 383 | 243 | 186 | 214 | 317 | 120 | 65 | 58 | 39 | 40 | 50 | 28 |
| | Subject 26 | 93 | 81 | 127 | 97 | 78 | 75 | 36 | 29 | 36 | 30 | 25 | 21 |
| | Subject 27 | 209 | 74 | 164 | 179 | 76 | 130 | 63 | 28 | 51 | 39 | 19 | 26 |
| | Subject 28 | 258 | 162 | 240 | 188 | 167 | 168 | 72 | 53 | 51 | 61 | 63 | 52 |
| | Subject 29 | 195 | 181 | 200 | 85 | 72 | 104 | 61 | 41 | 41 | 19 | 19 | 24 |
| | Subject 30 | 179 | 252 | 288 | 198 | 123 | 188 | 55 | 59 | 63 | 60 | 40 | 55 |
| | Subject 31 | 141 | 239 | 205 | 286 | 105 | 118 | 59 | 64 | 64 | 76 | 41 | 47 |
| | Subject 32 | 154 | 259 | 168 | 132 | 129 | 99 | 55 | 68 | 39 | 49 | 34 | 38 |
| Information Delay | Subject 33 | 301 | 246 | 227 | 115 | 323 | 203 | 39 | 44 | 31 | 17 | 45 | 21 |
| | Subject 34 | 342 | 300 | 153 | 198 | 96 | 134 | 83 | 66 | 49 | 52 | 34 | 48 |
| | Subject 35 | 302 | 220 | 108 | 207 | 142 | 96 | 79 | 55 | 34 | 49 | 51 | 32 |
| | Subject 36 | 497 | 106 | 127 | 184 | 74 | 118 | 81 | 33 | 39 | 44 | 18 | 32 |
| | Subject 37 | 438 | 170 | 323 | 217 | 138 | 191 | 81 | 61 | 66 | 46 | 34 | 35 |
| | Subject 38 | 282 | 118 | 170 | 138 | 95 | 50 | 73 | 41 | 49 | 47 | 30 | 21 |
| | Subject 39 | 180 | 154 | 242 | 155 | 372 | 284 | 52 | 42 | 48 | 48 | 64 | 76 |
| | Subject 40 | 245 | 321 | 134 | 101 | 84 | 108 | 44 | 62 | 26 | 23 | 21 | 26 |
| Both Delays (Without Pause) | Subject 41 | 342 | 300 | 153 | 198 | 96 | 134 | 83 | 66 | 49 | 52 | 34 | 48 |
| | Subject 42 | 278 | 238 | 379 | 441 | 189 | 194 | 31 | 29 | 44 | 48 | 23 | 27 |
| | Subject 43 | 357 | 294 | 204 | 133 | 166 | 130 | 91 | 81 | 72 | 61 | 61 | 56 |
| | Subject 44 | 233 | 268 | 303 | 158 | 100 | 116 | 36 | 38 | 40 | 29 | 25 | 27 |
| | Subject 45 | 355 | 500 | 208 | 245 | 285 | 156 | 71 | 74 | 66 | 69 | 67 | 50 |
| | Subject 46 | 335 | 389 | 313 | 257 | 277 | 115 | 91 | 85 | 89 | 78 | 72 | 52 |
| Both Delays (With Pause) | Subject 47 | 128 | 124 | 233 | 137 | 122 | 109 | 32 | 54 | 55 | 43 | 37 | 40 |
| | Subject 48 | 485 | 344 | 668 | 665 | 431 | 226 | 47 | 40 | 70 | 87 | 45 | 48 |
| | Subject 49 | 145 | 287 | 211 | 116 | 150 | 106 | 58 | 70 | 65 | 43 | 37 | 32 |
| | Subject 50 | 348 | 251 | 270 | 231 | 281 | 122 | 91 | 72 | 69 | 69 | 81 | 58 |
| | Subject 51 | 312 | 337 | 252 | 308 | 204 | 262 | 86 | 84 | 71 | 75 | 70 | 71 |
| | Subject 52 | 360 | 594 | 559 | 316 | 220 | 306 | 63 | 59 | 63 | 65 | 60 | 62 |
| | Subject 53 | 216 | 107 | 139 | 240 | 141 | 193 | 43 | 29 | 50 | 56 | 33 | 42 |
| Scuba Divers | Subject 54 | 111 | 68 | 61 | 28 | 70 | 41 | 36 | 30 | 17 | 10 | 18 | 18 |
| | Subject 55 | 66 | 40 | 28 | 21 | 18 | 34 | 16 | 17 | 13 | 7 | 7 | 19 |
| | Subject 56 | 103 | 42 | 50 | 36 | 51 | 51 | 27 | 15 | 13 | 10 | 13 | 12 |
| | Subject 57 | 120 | 105 | 156 | 87 | 74 | 59 | 42 | 46 | 45 | 38 | 35 | 30 |
| | Subject 58 | 212 | 291 | 115 | 145 | 67 | | 57 | 66 | 37 | 37 | 28 | |
| | Subject 59 | 187 | 142 | 74 | 145 | 114 | 131 | 64 | 47 | 34 | 55 | 42 | 46 |

Table E.36. Max-dev-10 and ±2 settling time scores obtained by Subject 17-59

| | | Maximum Deviation from 10 meters | | | | | | ±2 Settling Time | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No delay | Subject 17 | 5,6 | 2,4 | 2,0 | 2,7 | 3,6 | 2,5 | 90 | 59 | 50 | 81 | 90 | 38 |
| | Subject 18 | 10,2 | 10,3 | 10,4 | 3,2 | 10,3 | 2,6 | 90 | 90 | 90 | 75 | 48 | 90 |
| | Subject 19 | 3,3 | 3,4 | 1,8 | 2,5 | 2,3 | 2,3 | 65 | 89 | 0 | 90 | 33 | 20 |
| | Subject 20 | 7,2 | 4,0 | 1,3 | 2,1 | 1,8 | 1,8 | 90 | 90 | 0 | 44 | 0 | 0 |
| | Subject 21 | 7,9 | 4,4 | 2,8 | 6,9 | 2,4 | 6,3 | 90 | 86 | 89 | 90 | 71 | 40 |
| | Subject 22 | 3,2 | 3,7 | 1,5 | 2,4 | 1,0 | 3,0 | 90 | 90 | 0 | 15 | 0 | 84 |
| | Subject 23 | 10,9 | 10,7 | 3,9 | 4,0 | 2,7 | 1,5 | 90 | 90 | 54 | 55 | 72 | 0 |
| | Subject 24 | 1,3 | 2,8 | 1,9 | 2,8 | 2,6 | 1,8 | 0 | 56 | 0 | 33 | 73 | 0 |
| Material Delay | Subject 25 | 10,9 | 10,1 | 5,6 | 6,1 | 10,0 | 3,7 | 90 | 90 | 90 | 86 | 90 | 89 |
| | Subject 26 | 2,9 | 2,9 | 4,2 | 3,2 | 2,4 | 4,0 | 90 | 86 | 58 | 88 | 70 | 80 |
| | Subject 27 | 10,4 | 2,8 | 10,6 | 6,6 | 3,4 | 4,8 | 90 | 35 | 90 | 86 | 61 | 44 |
| | Subject 28 | 7,0 | 7,2 | 7,7 | 6,7 | 7,3 | 5,6 | 90 | 90 | 82 | 90 | 90 | 90 |
| | Subject 29 | 10,4 | 4,5 | 6,3 | 2,9 | 3,0 | 5,1 | 90 | 90 | 90 | 87 | 90 | 89 |
| | Subject 30 | 5,4 | 9,7 | 10,1 | 6,4 | 3,5 | 7,2 | 90 | 90 | 90 | 90 | 81 | 88 |
| | Subject 31 | 8,0 | 10,4 | 8,1 | 11,0 | 3,3 | 4,7 | 90 | 90 | 88 | 90 | 90 | 77 |
| | Subject 32 | 7,1 | 10,7 | 6,3 | 6,2 | 4,8 | 3,5 | 90 | 90 | 80 | 86 | 90 | 62 |
| Information Delay | Subject 33 | 10,5 | 10,5 | 9,9 | 5,2 | 10,7 | 6,3 | 83 | 89 | 55 | 83 | 80 | 88 |
| | Subject 34 | 10,6 | 10,1 | 7,2 | 7,2 | 3,6 | 3,3 | 90 | 90 | 90 | 90 | 90 | 84 |
| | Subject 35 | 10,8 | 6,3 | 3,6 | 8,2 | 3,9 | 2,5 | 90 | 90 | 90 | 90 | 90 | 71 |
| | Subject 36 | 10,8 | 4,7 | 4,3 | 9,4 | 2,1 | 5,1 | 90 | 82 | 88 | 90 | 61 | 90 |
| | Subject 37 | 10,7 | 5,5 | 10,8 | 7,9 | 4,9 | 8,7 | 90 | 83 | 90 | 90 | 90 | 90 |
| | Subject 38 | 10,6 | 3,9 | 7,5 | 5,3 | 4,1 | 2,5 | 90 | 88 | 90 | 90 | 62 | 38 |
| | Subject 39 | 6,9 | 10,5 | 10,7 | 10,0 | 11,1 | 10,7 | 90 | 90 | 88 | 90 | 90 | 90 |
| | Subject 40 | 9,2 | 10,5 | 4,2 | 2,4 | 3,8 | 4,0 | 87 | 90 | 90 | 67 | 53 | 87 |
| Both Delays (Without Pause) | Subject 41 | 10,6 | 10,1 | 7,2 | 7,2 | 3,6 | 3,3 | 90 | 90 | 90 | 90 | 90 | 84 |
| | Subject 42 | 10,3 | 7,0 | 10,0 | 10,5 | 6,1 | 5,7 | 88 | 90 | 90 | 89 | 90 | 90 |
| | Subject 43 | 10,8 | 10,2 | 6,6 | 5,7 | 7,2 | 4,7 | 90 | 90 | 86 | 90 | 83 | 90 |
| | Subject 44 | 7,1 | 8,8 | 10,5 | 7,8 | 2,7 | 3,3 | 90 | 80 | 70 | 90 | 88 | 89 |
| | Subject 45 | 10,6 | 11,5 | 10,4 | 10,4 | 10,2 | 7,0 | 88 | 90 | 90 | 90 | 90 | 90 |
| | Subject 46 | 10,5 | 10,7 | 11,2 | 10,0 | 10,4 | 3,6 | 90 | 90 | 90 | 90 | 90 | 89 |
| Both Delays (With Pause) | Subject 47 | 4,5 | 4,7 | 8,8 | 6,5 | 5,7 | 4,3 | 81 | 78 | 90 | 85 | 90 | 85 |
| | Subject 48 | 10,6 | 10,4 | 14,0 | 19,7 | 10,7 | 7,0 | 90 | 88 | 90 | 90 | 90 | 90 |
| | Subject 49 | 6,7 | 10,7 | 10,6 | 3,7 | 4,7 | 3,1 | 90 | 83 | 90 | 89 | 77 | 87 |
| | Subject 50 | 10,7 | 9,2 | 10,9 | 10,6 | 10,7 | 3,6 | 88 | 81 | 90 | 90 | 90 | 80 |
| | Subject 51 | 10,5 | 10,8 | 7,9 | 9,7 | 9,1 | 10,1 | 90 | 90 | 89 | 90 | 90 | 89 |
| | Subject 52 | 8,6 | 11,1 | 15,6 | 10,5 | 3,7 | 10,4 | 90 | 90 | 90 | 90 | 90 | 90 |
| | Subject 53 | 5,3 | 4,3 | 6,7 | 10,8 | 6,5 | 6,4 | 87 | 82 | 87 | 90 | 90 | 90 |
| Scuba Divers | Subject 54 | 3,9 | 2,2 | 2,4 | 1,0 | 2,5 | 2,2 | 90 | 87 | 59 | 0 | 70 | 85 |
| | Subject 55 | 2,3 | 1,7 | 1,2 | 0,8 | 0,8 | 1,7 | 24 | 0 | 0 | 0 | 0 | 0 |
| | Subject 56 | 3,0 | 1,3 | 1,8 | 1,2 | 1,4 | 1,9 | 61 | 0 | 0 | 0 | 0 | 0 |
| | Subject 57 | 3,3 | 3,8 | 10,1 | 3,1 | 3,3 | 1,9 | 85 | 90 | 65 | 83 | 29 | 0 |
| | Subject 58 | 8,7 | 10,7 | 3,9 | 6,2 | 2,2 | | 90 | 90 | 90 | 90 | 81 | |
| | Subject 59 | 6,1 | 5,5 | 2,6 | 6,2 | 4,0 | 5,5 | 90 | 83 | 80 | 90 | 90 | 86 |

Table E.37 Dev-mean-10mt and dev-area-mean scores obtained by Subject 17-59

| | | Deviation of Mean from 10 meters | | | | | | Deviation Area from Mean | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No delay | Subject 17 | 0,43 | 0,48 | 0,76 | 0,82 | 1,40 | 0,32 | 88 | 70 | 30 | 65 | 61 | 81 |
| | Subject 18 | 2,02 | 1,10 | 0,73 | 0,49 | 1,10 | 0,17 | 222 | 199 | 138 | 85 | 166 | 67 |
| | Subject 19 | 0,31 | 0,93 | 0,43 | 0,41 | 0,39 | 0,18 | 70 | 52 | 54 | 71 | 57 | 69 |
| | Subject 20 | 1,09 | 0,98 | 0,17 | 0,04 | 0,09 | 0,30 | 217 | 126 | 39 | 51 | 37 | 50 |
| | Subject 21 | 1,79 | 0,70 | 0,39 | 0,99 | 0,50 | 1,32 | 183 | 120 | 70 | 126 | 88 | 179 |
| | Subject 22 | 0,06 | 0,69 | 0,01 | 0,00 | 0,01 | 0,37 | 85 | 89 | 47 | 56 | 33 | 71 |
| | Subject 23 | 1,64 | 2,29 | 0,33 | 0,40 | 0,01 | 0,27 | 299 | 233 | 97 | 87 | 77 | 51 |
| | Subject 24 | 0,18 | 0,51 | 0,53 | 0,61 | 0,27 | 0,19 | 43 | 62 | 41 | 66 | 78 | 55 |
| Material Delay | Subject 25 | 3,47 | 1,88 | 1,32 | 0,31 | 2,17 | 0,04 | 358 | 237 | 169 | 216 | 302 | 120 |
| | Subject 26 | 0,44 | 0,53 | 0,17 | 0,18 | 0,66 | 0,52 | 89 | 77 | 128 | 98 | 61 | 74 |
| | Subject 27 | 2,02 | 0,02 | 0,14 | 1,12 | 0,58 | 0,40 | 178 | 75 | 165 | 179 | 70 | 134 |
| | Subject 28 | 2,17 | 0,60 | 1,44 | 0,90 | 0,36 | 0,02 | 211 | 160 | 233 | 188 | 170 | 168 |
| | Subject 29 | 0,54 | 1,09 | 0,23 | 0,45 | 0,10 | 0,86 | 204 | 173 | 200 | 89 | 72 | 106 |
| | Subject 30 | 0,67 | 0,70 | 0,77 | 0,51 | 0,62 | 0,04 | 176 | 244 | 271 | 194 | 114 | 188 |
| | Subject 31 | 0,27 | 1,90 | 0,18 | 0,67 | 0,30 | 0,22 | 140 | 236 | 204 | 292 | 103 | 120 |
| | Subject 32 | 1,17 | 1,00 | 1,07 | 0,43 | 0,35 | 0,43 | 145 | 277 | 160 | 138 | 130 | 97 |
| Information Delay | Subject 33 | 2,90 | 0,98 | 1,73 | 0,68 | 1,36 | 1,43 | 292 | 279 | 237 | 128 | 340 | 197 |
| | Subject 34 | 2,76 | 3,08 | 1,23 | 2,07 | 0,50 | 0,02 | 304 | 224 | 136 | 130 | 93 | 134 |
| | Subject 35 | 1,21 | 0,97 | 0,18 | 0,33 | 0,49 | 0,54 | 305 | 216 | 108 | 207 | 139 | 90 |
| | Subject 36 | 3,15 | 0,27 | 0,45 | 1,52 | 0,02 | 0,69 | 449 | 108 | 130 | 195 | 74 | 123 |
| | Subject 37 | 4,46 | 0,74 | 2,98 | 0,10 | 0,65 | 1,39 | 318 | 164 | 257 | 219 | 136 | 182 |
| | Subject 38 | 1,19 | 0,69 | 0,84 | 1,26 | 0,30 | 0,21 | 286 | 107 | 171 | 120 | 90 | 53 |
| | Subject 39 | 1,40 | 0,62 | 1,16 | 1,01 | 2,43 | 0,16 | 175 | 168 | 243 | 172 | 347 | 286 |
| | Subject 40 | 0,85 | 1,17 | 1,13 | 0,59 | 0,51 | 0,63 | 248 | 348 | 113 | 89 | 83 | 112 |
| Both Delays (Without Pause) | Subject 41 | 2,76 | 3,08 | 1,23 | 2,07 | 0,50 | 0,02 | 304 | 224 | 136 | 130 | 93 | 134 |
| | Subject 42 | 2,59 | 0,84 | 0,04 | 0,73 | 1,74 | 1,72 | 268 | 229 | 378 | 445 | 165 | 154 |
| | Subject 43 | 3,45 | 2,40 | 0,94 | 0,12 | 0,68 | 0,28 | 295 | 286 | 205 | 135 | 172 | 131 |
| | Subject 44 | 0,25 | 0,91 | 1,57 | 1,15 | 0,19 | 0,10 | 236 | 276 | 316 | 164 | 100 | 118 |
| | Subject 45 | 3,08 | 1,90 | 1,99 | 1,89 | 2,83 | 0,71 | 279 | 499 | 188 | 239 | 235 | 161 |
| | Subject 46 | 2,31 | 3,01 | 1,11 | 1,03 | 0,62 | 0,57 | 319 | 352 | 322 | 262 | 283 | 110 |
| Both Delays (With Pause) | Subject 47 | 0,59 | 0,86 | 2,04 | 0,89 | 0,54 | 0,11 | 123 | 118 | 217 | 138 | 119 | 110 |
| | Subject 48 | 3,35 | 1,51 | 1,92 | 4,75 | 1,54 | 0,42 | 430 | 373 | 650 | 605 | 401 | 233 |
| | Subject 49 | 0,72 | 1,76 | 0,75 | 0,03 | 0,82 | 0,31 | 138 | 272 | 217 | 117 | 150 | 104 |
| | Subject 50 | 2,89 | 1,90 | 0,41 | 1,61 | 1,54 | 0,46 | 316 | 240 | 281 | 239 | 295 | 121 |
| | Subject 51 | 2,42 | 2,47 | 2,16 | 3,14 | 1,60 | 2,26 | 308 | 315 | 229 | 247 | 201 | 226 |
| | Subject 52 | 0,01 | 2,48 | 1,00 | 3,10 | 0,59 | 2,55 | 360 | 598 | 554 | 268 | 228 | 258 |
| | Subject 53 | 0,64 | 0,52 | 0,67 | 0,27 | 0,39 | 1,08 | 209 | 102 | 137 | 245 | 141 | 196 |
| Scuba Divers | Subject 54 | 0,87 | 0,23 | 0,49 | 0,05 | 0,59 | 0,08 | 96 | 66 | 56 | 28 | 62 | 41 |
| | Subject 55 | 0,40 | 0,12 | 0,04 | 0,00 | 0,02 | 0,08 | 66 | 41 | 28 | 21 | 18 | 34 |
| | Subject 56 | 0,51 | 0,11 | 0,47 | 0,32 | 0,35 | 0,02 | 102 | 43 | 42 | 29 | 43 | 51 |
| | Subject 57 | 0,38 | 0,60 | 1,19 | 0,15 | 0,09 | 0,10 | 121 | 103 | 170 | 88 | 75 | 59 |
| | Subject 58 | 1,89 | 1,50 | 0,70 | 0,75 | 0,12 | | 199 | 298 | 115 | 151 | 69 | |
| | Subject 59 | 1,73 | 0,40 | 0,01 | 0,38 | 0,05 | 0,44 | 152 | 147 | 74 | 149 | 114 | 134 |

Table E.38. Max-amp-osc and Caisson-RI scores obtained by Subject 17-59

| | | Maximum Amplitude of Oscillations | | | | | | Caisson Disease Risk Index | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No delay | Subject 17 | 7,4 | 3,4 | 1,9 | 2,8 | 2,8 | 3,6 | 7,7 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | Subject 18 | 12,6 | 14,5 | 13,3 | 5,3 | 11,3 | 5,1 | 31,4 | 36,2 | 28,8 | 7,6 | 18,6 | 10,0 |
| | Subject 19 | 3,8 | 3,5 | 3,1 | 3,5 | 3,2 | 3,5 | 0,4 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | Subject 20 | 9,3 | 5,2 | 2,1 | 3,3 | 3,2 | 3,2 | 16,7 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | Subject 21 | 8,8 | 7,0 | 3,8 | 7,3 | 3,7 | 6,9 | 29,1 | 11,6 | 3,3 | 15,4 | 1,7 | 0,0 |
| | Subject 22 | 4,8 | 4,9 | 2,5 | 4,3 | 1,7 | 4,7 | 1,5 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | Subject 23 | 17,1 | 12,3 | 6,0 | 5,7 | 4,9 | 2,6 | 64,8 | 42,9 | 1,2 | 0,6 | 2,2 | 0,0 |
| | Subject 24 | 2,5 | 3,9 | 1,9 | 3,3 | 4,7 | 2,8 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Material Delay | Subject 25 | 14,8 | 14,0 | 9,2 | 11,3 | 11,4 | 6,0 | 39,7 | 27,8 | 9,3 | 7,7 | 16,9 | 2,1 |
| | Subject 26 | 5,7 | 4,1 | 7,8 | 5,5 | 2,8 | 5,0 | 3,4 | 0,0 | 7,8 | 2,3 | 0,0 | 0,0 |
| | Subject 27 | 10,5 | 4,6 | 16,1 | 8,3 | 4,0 | 7,4 | 31,3 | 0,0 | 33,9 | 3,1 | 0,0 | 0,0 |
| | Subject 28 | 8,9 | 10,4 | 13,3 | 8,9 | 10,5 | 9,9 | 34,9 | 23,7 | 17,5 | 24,4 | 34,2 | 19,1 |
| | Subject 29 | 12,5 | 7,6 | 11,6 | 3,8 | 5,5 | 6,0 | 22,6 | 3,4 | 5,2 | 0,0 | 0,0 | 0,0 |
| | Subject 30 | 9,5 | 12,8 | 16,0 | 12,7 | 6,0 | 10,6 | 16,1 | 27,2 | 35,4 | 30,1 | 4,2 | 25,3 |
| | Subject 31 | 13,3 | 13,8 | 13,5 | 18,7 | 4,8 | 8,0 | 31,9 | 29,6 | 29,1 | 62,3 | 3,6 | 7,6 |
| | Subject 32 | 8,4 | 15,4 | 6,6 | 8,4 | 7,2 | 6,0 | 15,8 | 34,3 | 4,1 | 13,5 | 6,4 | 3,8 |
| Information Delay | Subject 33 | 12,6 | 14,9 | 12,2 | 6,1 | 17,0 | 8,3 | 13,5 | 15,4 | 0,0 | 0,0 | 24,0 | 1,5 |
| | Subject 34 | 15,0 | 10,1 | 8,6 | 8,6 | 5,4 | 6,5 | 54,0 | 26,0 | 13,4 | 16,8 | 4,2 | 9,6 |
| | Subject 35 | 18,0 | 9,5 | 5,6 | 11,5 | 6,7 | 4,3 | 48,8 | 29,7 | 2,8 | 13,5 | 10,8 | 1,8 |
| | Subject 36 | 15,9 | 6,9 | 7,9 | 10,6 | 3,0 | 7,7 | 52,2 | 2,8 | 5,0 | 20,6 | 0,0 | 7,8 |
| | Subject 37 | 13,3 | 8,0 | 10,9 | 12,7 | 5,0 | 6,4 | 53,6 | 20,6 | 30,7 | 9,6 | 3,9 | 11,0 |
| | Subject 38 | 16,1 | 5,2 | 9,0 | 5,6 | 6,1 | 3,4 | 40,9 | 5,7 | 18,6 | 12,0 | 2,7 | 3,1 |
| | Subject 39 | 8,9 | 13,9 | 17,0 | 9,6 | 18,5 | 15,4 | 11,2 | 19,7 | 27,0 | 20,4 | 58,8 | 62,2 |
| | Subject 40 | 11,1 | 15,1 | 5,6 | 3,5 | 5,8 | 5,5 | 2,3 | 32,0 | 3,2 | 0,9 | 0,0 | 0,0 |
| Both Delays (Without Pause) | Subject 41 | 15,0 | 10,1 | 8,6 | 8,6 | 5,4 | 6,5 | 54,0 | 26,0 | 13,4 | 16,8 | 4,2 | 9,6 |
| | Subject 42 | 11,6 | 8,8 | 19,9 | 20,1 | 6,5 | 8,0 | 0,6 | 0,0 | 0,0 | 16,7 | 0,0 | 0,1 |
| | Subject 43 | 13,4 | 13,2 | 9,4 | 8,1 | 9,4 | 6,9 | 75,8 | 51,8 | 36,9 | 24,1 | 23,5 | 14,5 |
| | Subject 44 | 11,8 | 13,0 | 14,3 | 10,1 | 5,1 | 5,4 | 0,0 | 6,4 | 12,8 | 0,0 | 1,7 | 0,0 |
| | Subject 45 | 16,0 | 22,9 | 11,0 | 14,3 | 11,8 | 9,7 | 40,9 | 81,2 | 33,7 | 41,2 | 34,3 | 17,6 |
| | Subject 46 | 12,8 | 16,6 | 15,4 | 11,9 | 15,4 | 6,0 | 56,2 | 73,1 | 80,3 | 52,1 | 39,8 | 9,7 |
| Both Delays (With Pause) | Subject 47 | 6,1 | 5,7 | 11,1 | 8,5 | 9,1 | 6,1 | 0,0 | 13,6 | 24,1 | 11,0 | 11,0 | 1,3 |
| | Subject 48 | 15,3 | 16,1 | 24,7 | 30,8 | 21,0 | 13,9 | 16,2 | 2,3 | 51,6 | 92,2 | 0,0 | 10,2 |
| | Subject 49 | 8,8 | 16,5 | 14,8 | 6,7 | 6,4 | 6,0 | 15,9 | 44,9 | 35,9 | 7,9 | 2,4 | 8,8 |
| | Subject 50 | 14,4 | 13,2 | 16,8 | 14,3 | 15,5 | 6,5 | 71,5 | 39,7 | 45,0 | 44,2 | 62,0 | 17,2 |
| | Subject 51 | 12,7 | 16,1 | 11,2 | 10,4 | 11,3 | 13,9 | 58,8 | 69,6 | 36,0 | 42,9 | 31,3 | 33,9 |
| | Subject 52 | 12,8 | 21,5 | 26,7 | 12,4 | 6,6 | 10,5 | 30,1 | 55,4 | 69,5 | 30,6 | 26,1 | 10,5 |
| | Subject 53 | 10,4 | 5,9 | 9,4 | 15,8 | 10,7 | 10,8 | 2,5 | 2,4 | 13,5 | 30,8 | 2,8 | 2,9 |
| Scuba Divers | Subject 54 | 5,2 | 3,8 | 2,9 | 1,7 | 2,9 | 4,2 | 3,2 | 0,0 | 0,0 | 0,0 | 0,0 | 2,0 |
| | Subject 55 | 3,0 | 2,4 | 2,0 | 1,2 | 1,0 | 2,4 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | Subject 56 | 4,8 | 2,1 | 1,7 | 1,5 | 2,3 | 3,4 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | Subject 57 | 6,0 | 5,0 | 10,1 | 4,3 | 5,8 | 3,1 | 7,6 | 8,3 | 11,6 | 2,8 | 2,6 | 0,0 |
| | Subject 58 | 10,3 | 13,5 | 4,8 | 7,1 | 3,3 | | 19,6 | 42,3 | 2,7 | 5,7 | 0,8 | |
| | Subject 59 | 7,8 | 6,5 | 4,2 | 10,1 | 5,6 | 7,4 | 27,4 | 13,1 | 0,0 | 17,6 | 5,2 | 12,9 |

# APPENDIX F: GAME RESULTS

The sequence of trials are row-wise; from left to right.

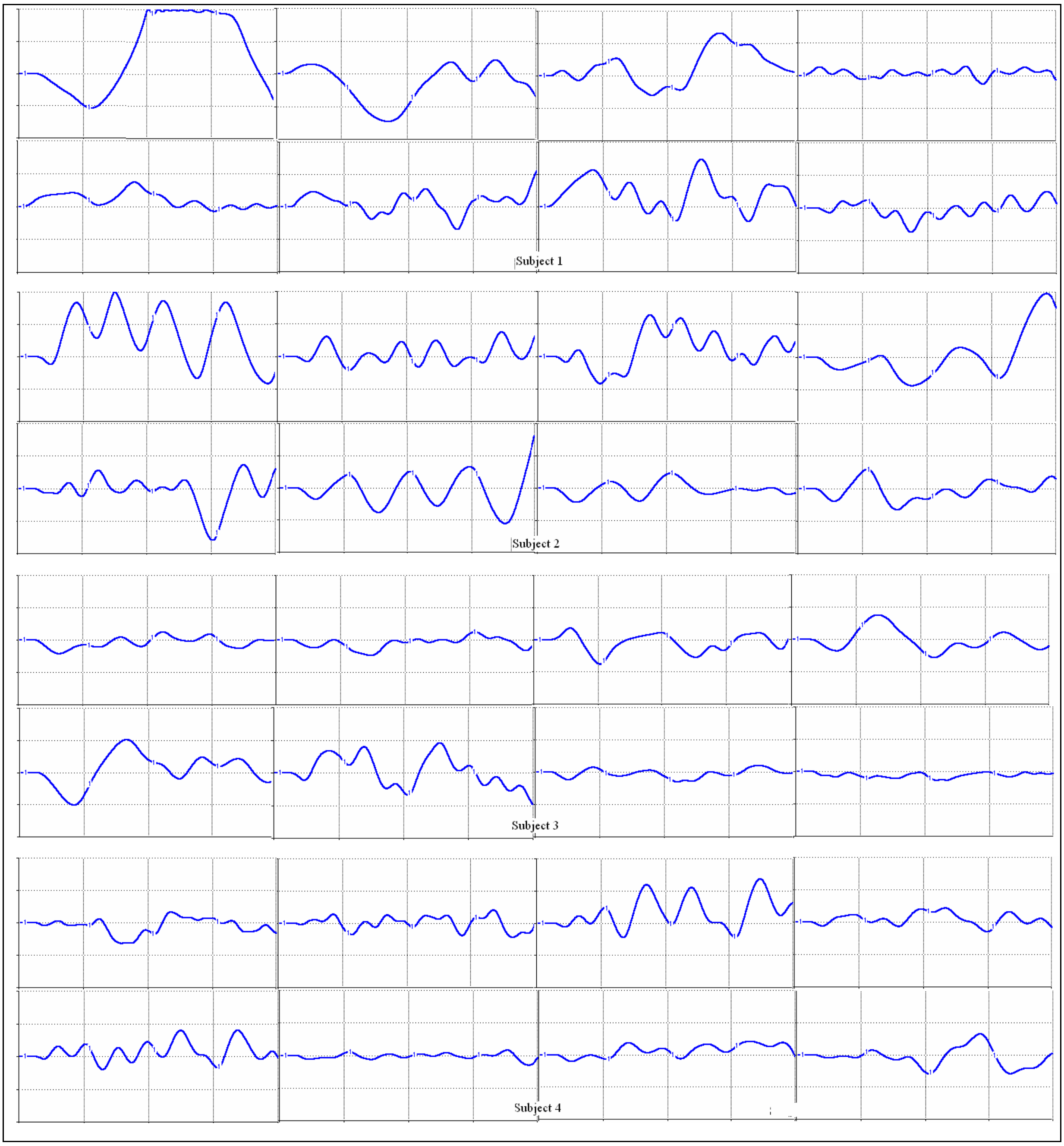



Figure F.1. Game results of Subject 1 to Subject 4

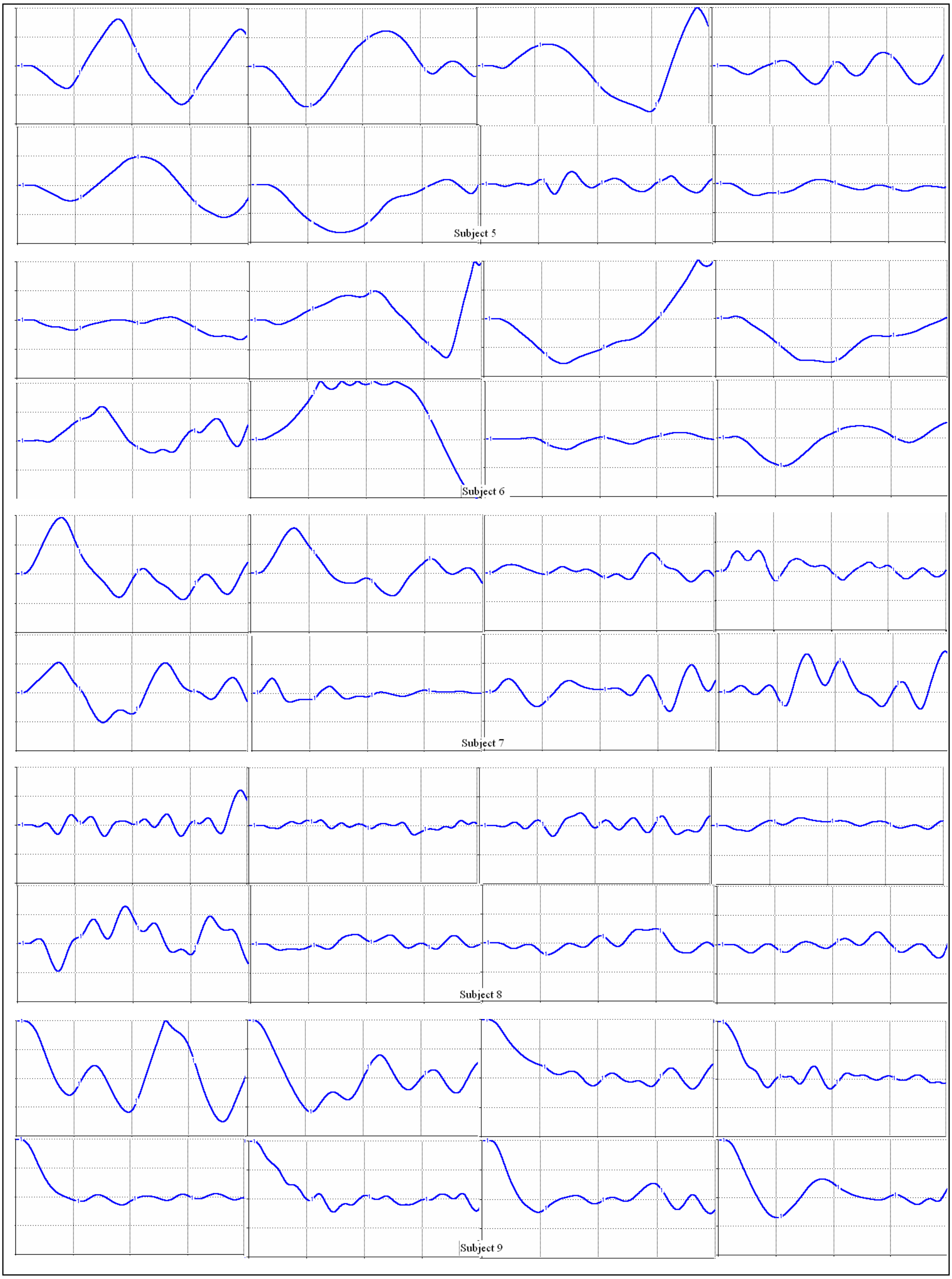



Figure F.2. Game results of Subject 5 to Subject 9

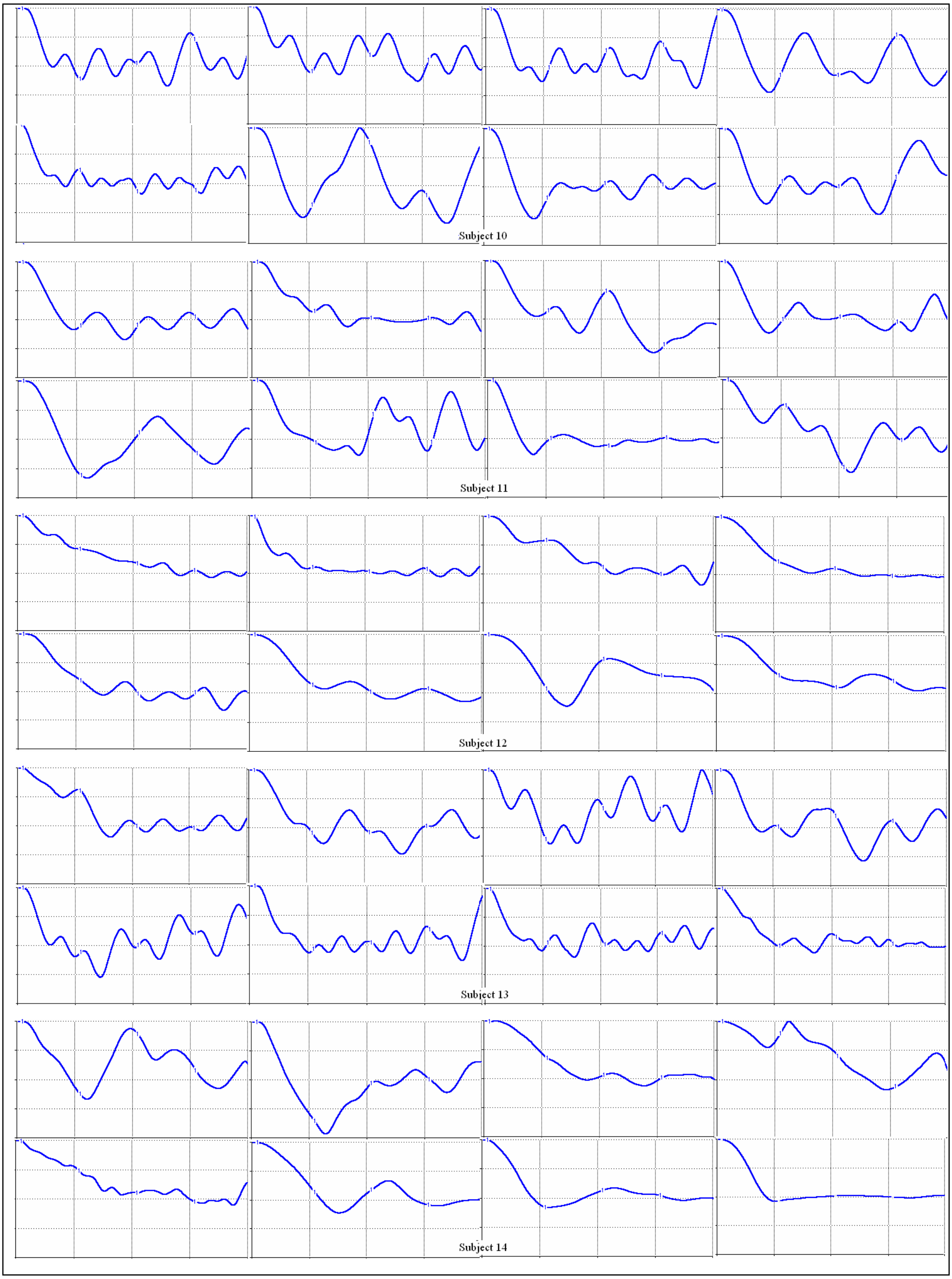



Figure F.3. Game results of Subject 10 to Subject 14

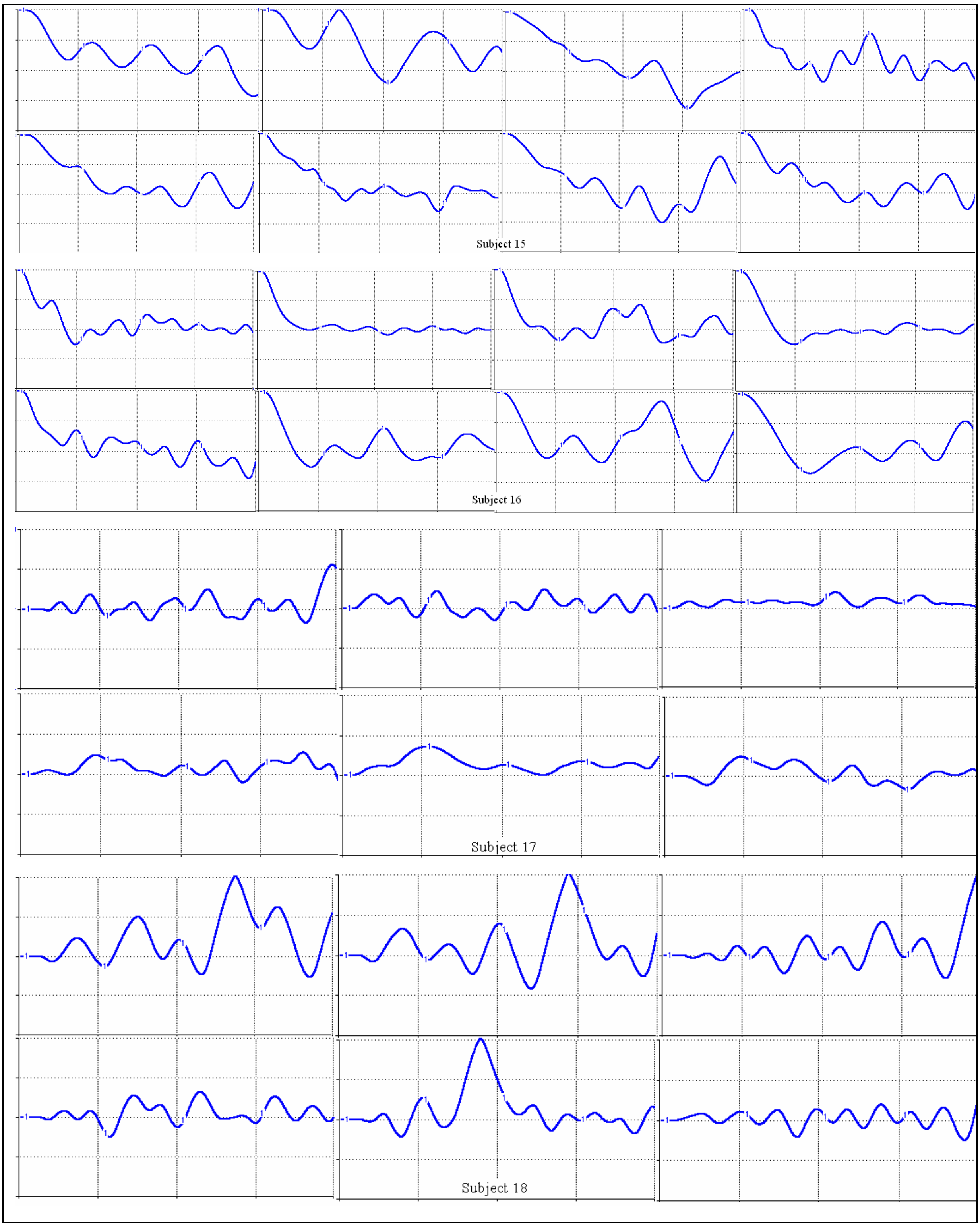



Figure F.4. Game results of Subject 15 to Subject 18

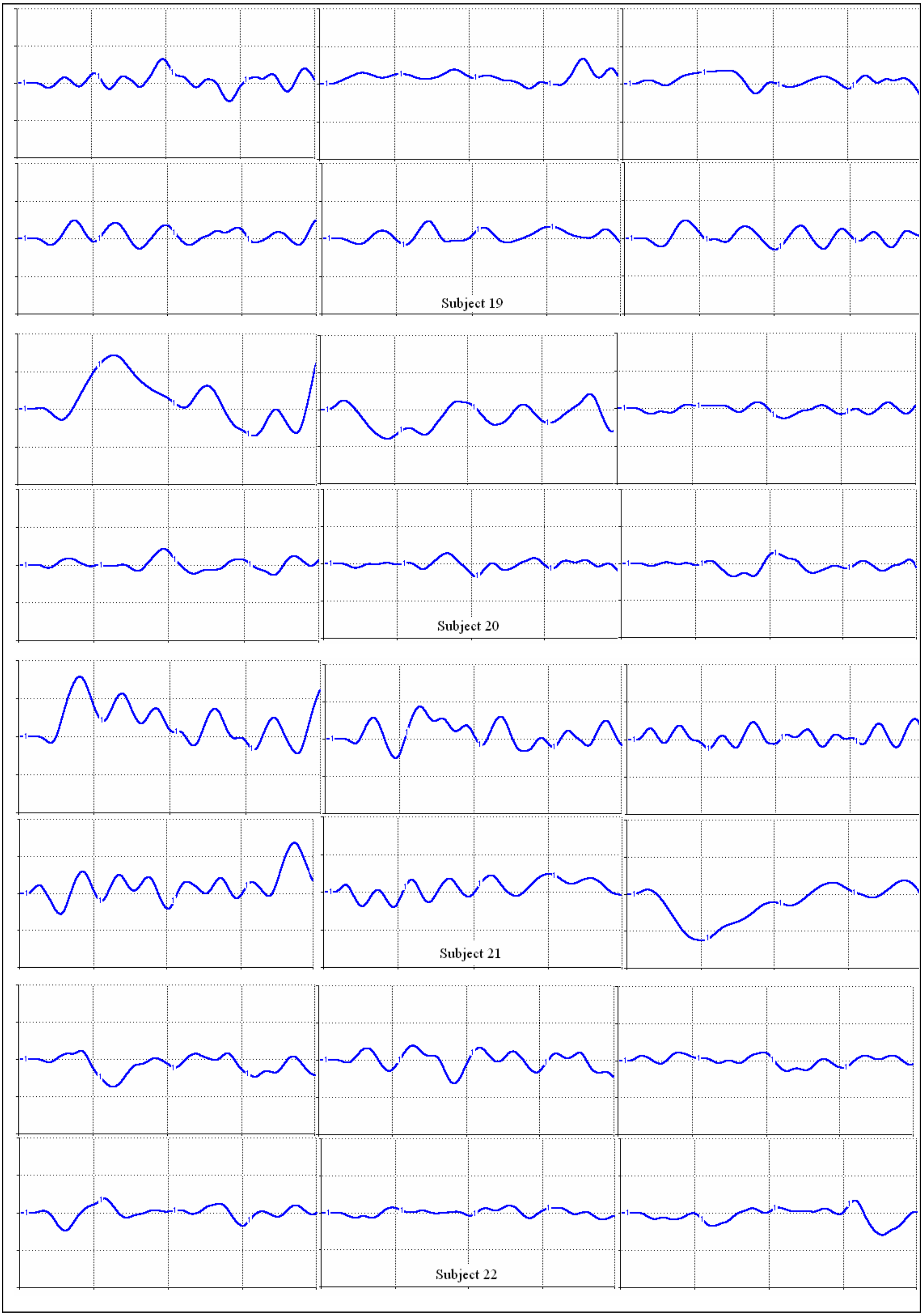



Figure F.5. Game results of Subject 19 to Subject 22

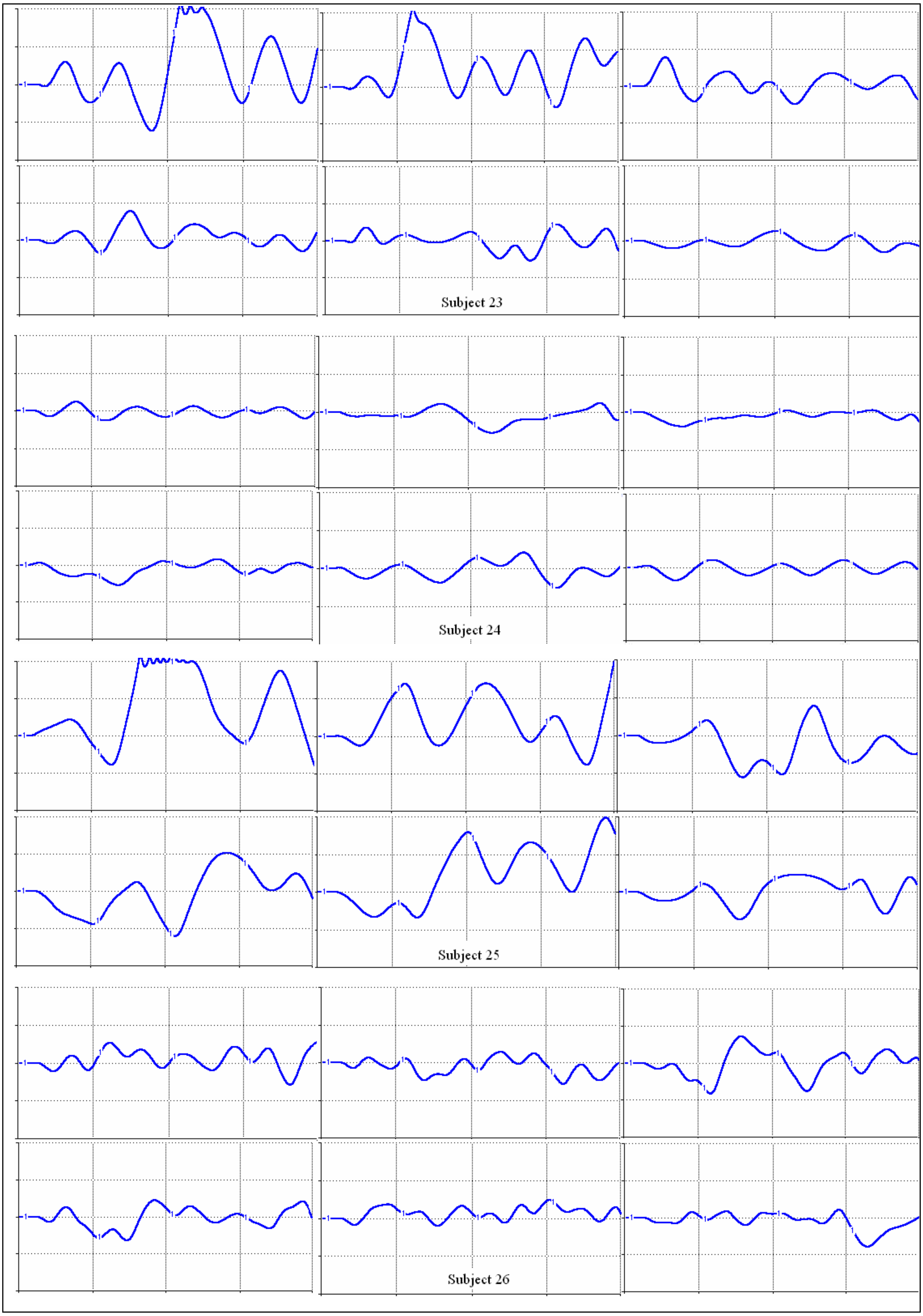



Figure F.6. Game results of Subject 23 to Subject 26

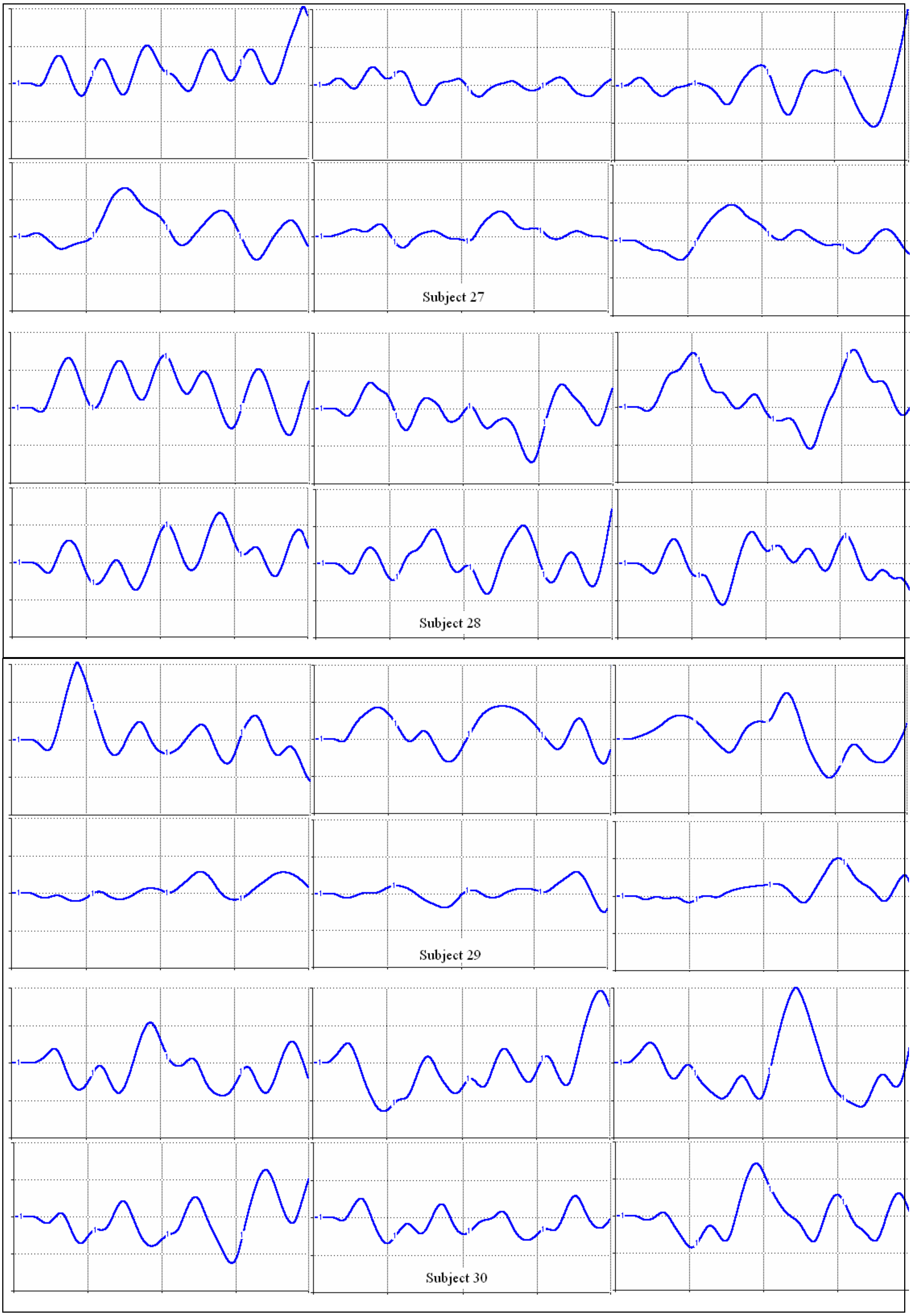



Figure F.7. Game results of Subject 27 to Subject 30

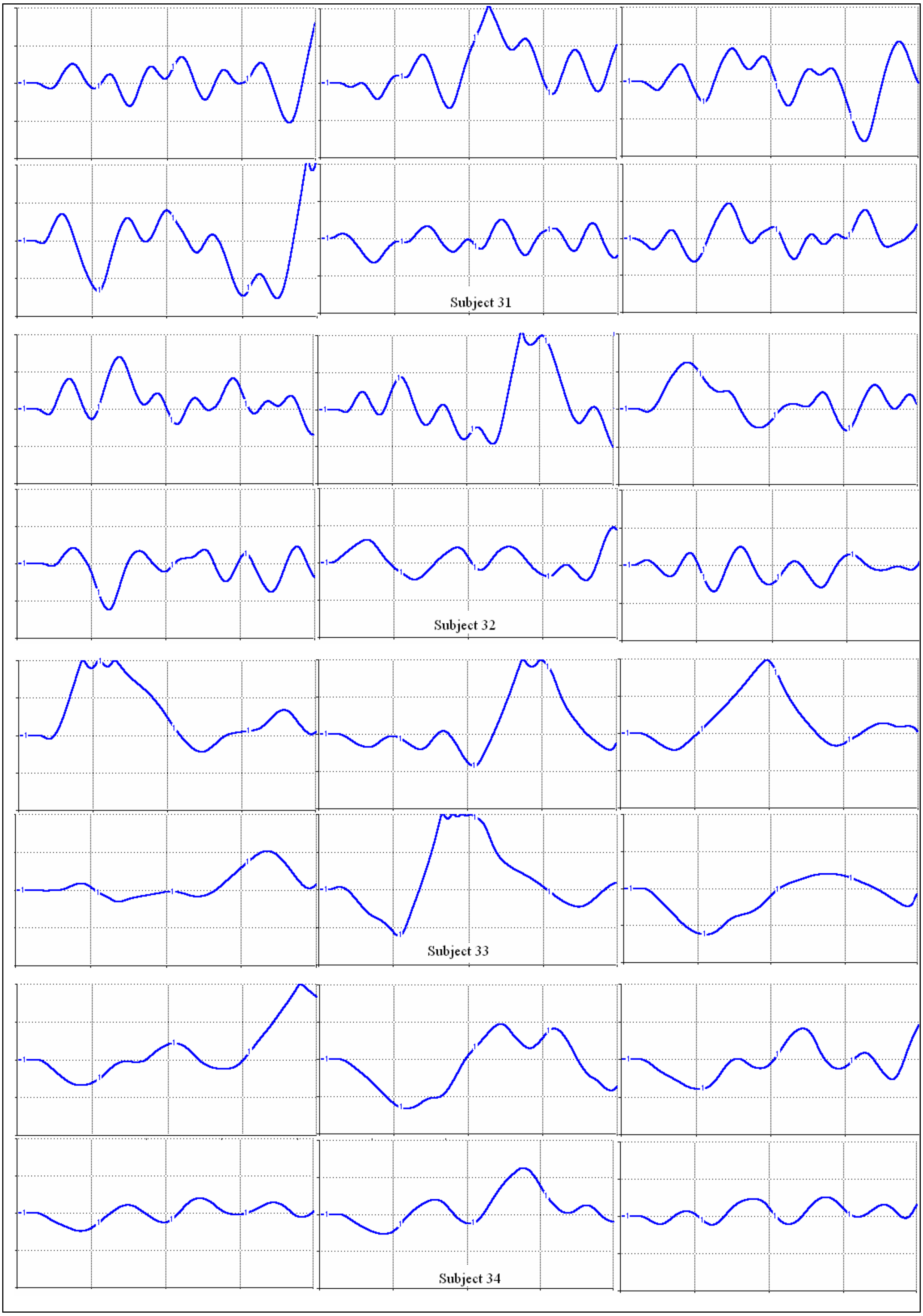



Figure F.8. Game results of Subject 31 to Subject 34

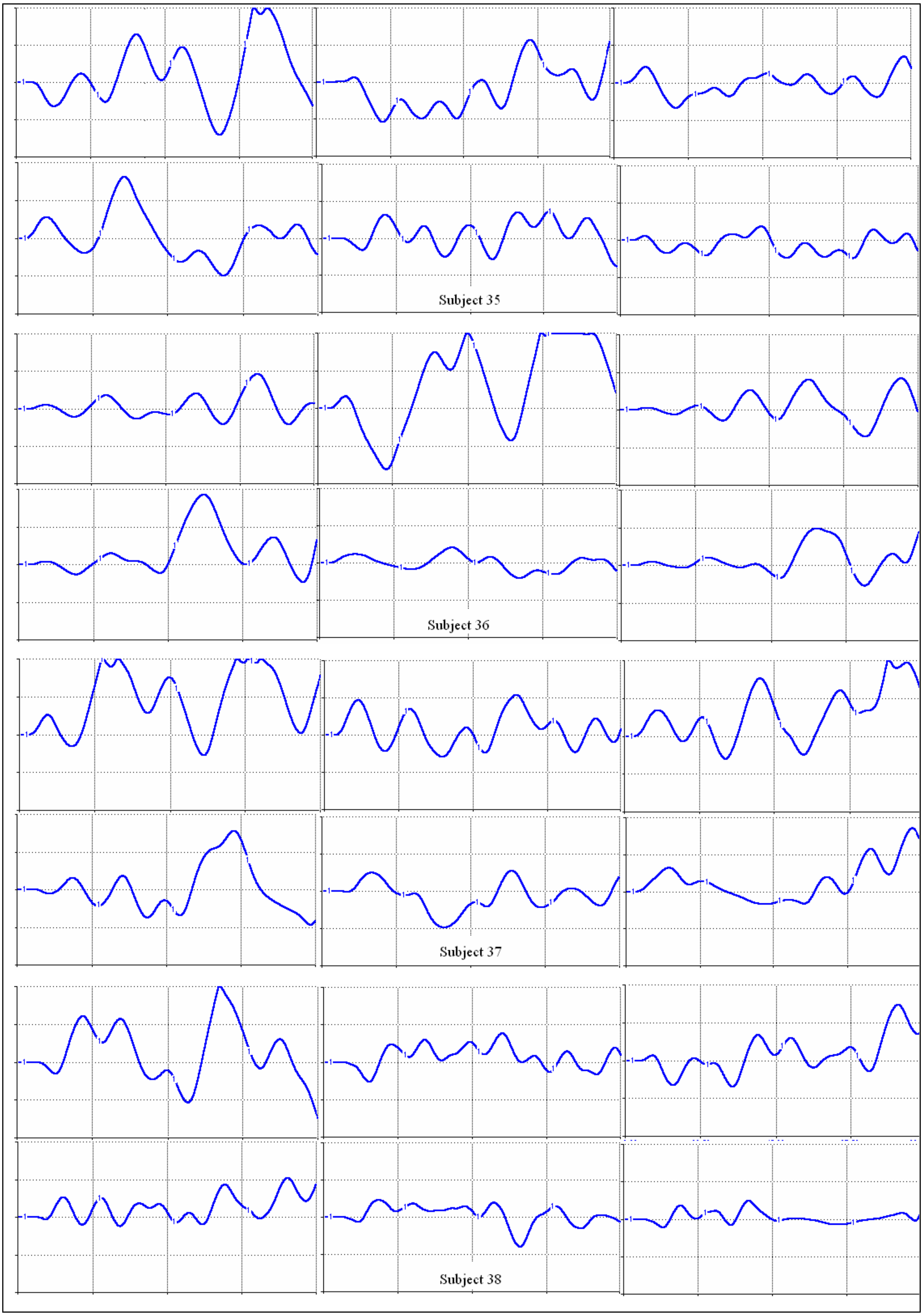



Figure F.9. Game results of Subject 35 to Subject 38

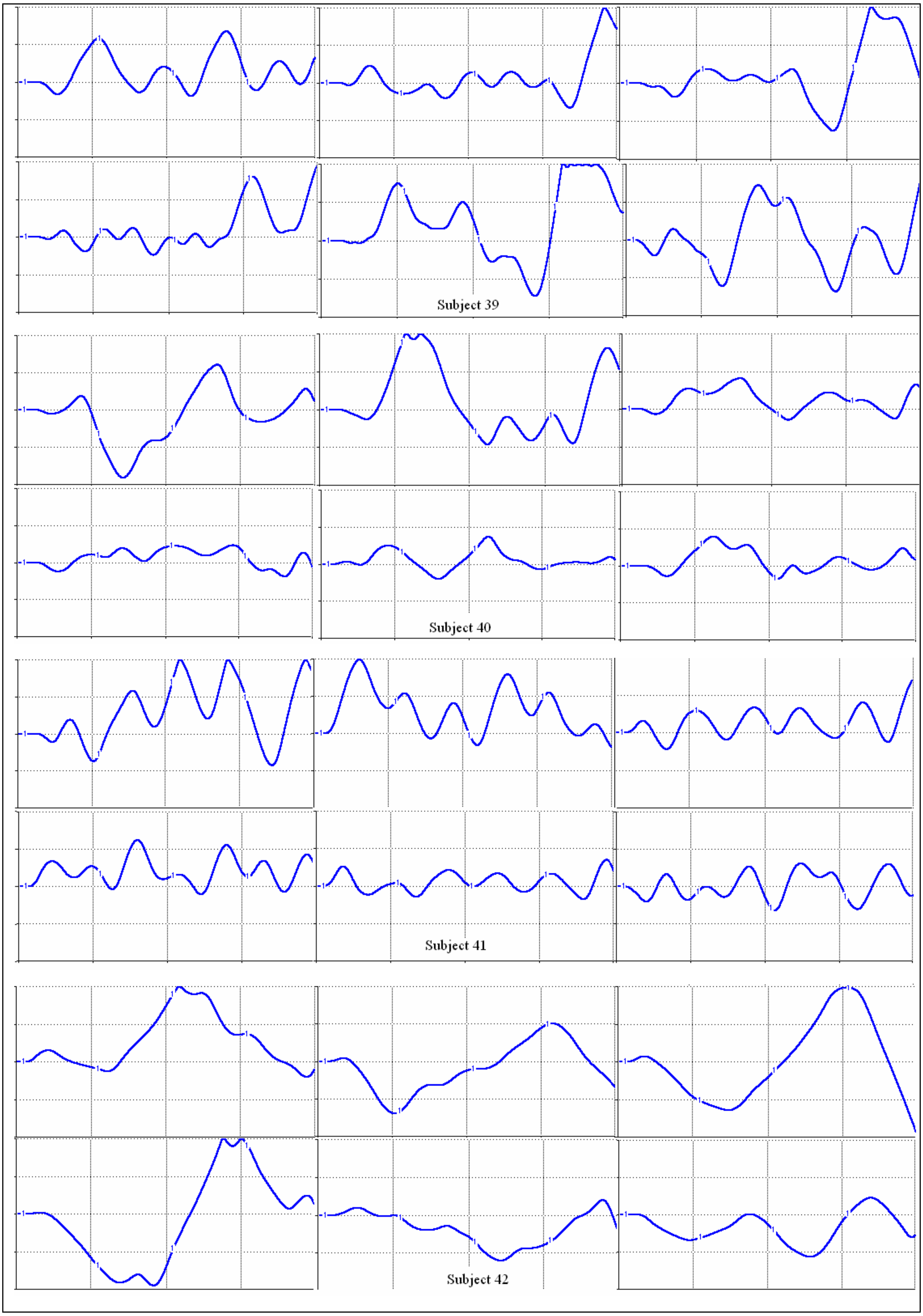



Figure F.10. Game results of Subject 39 to Subject 42

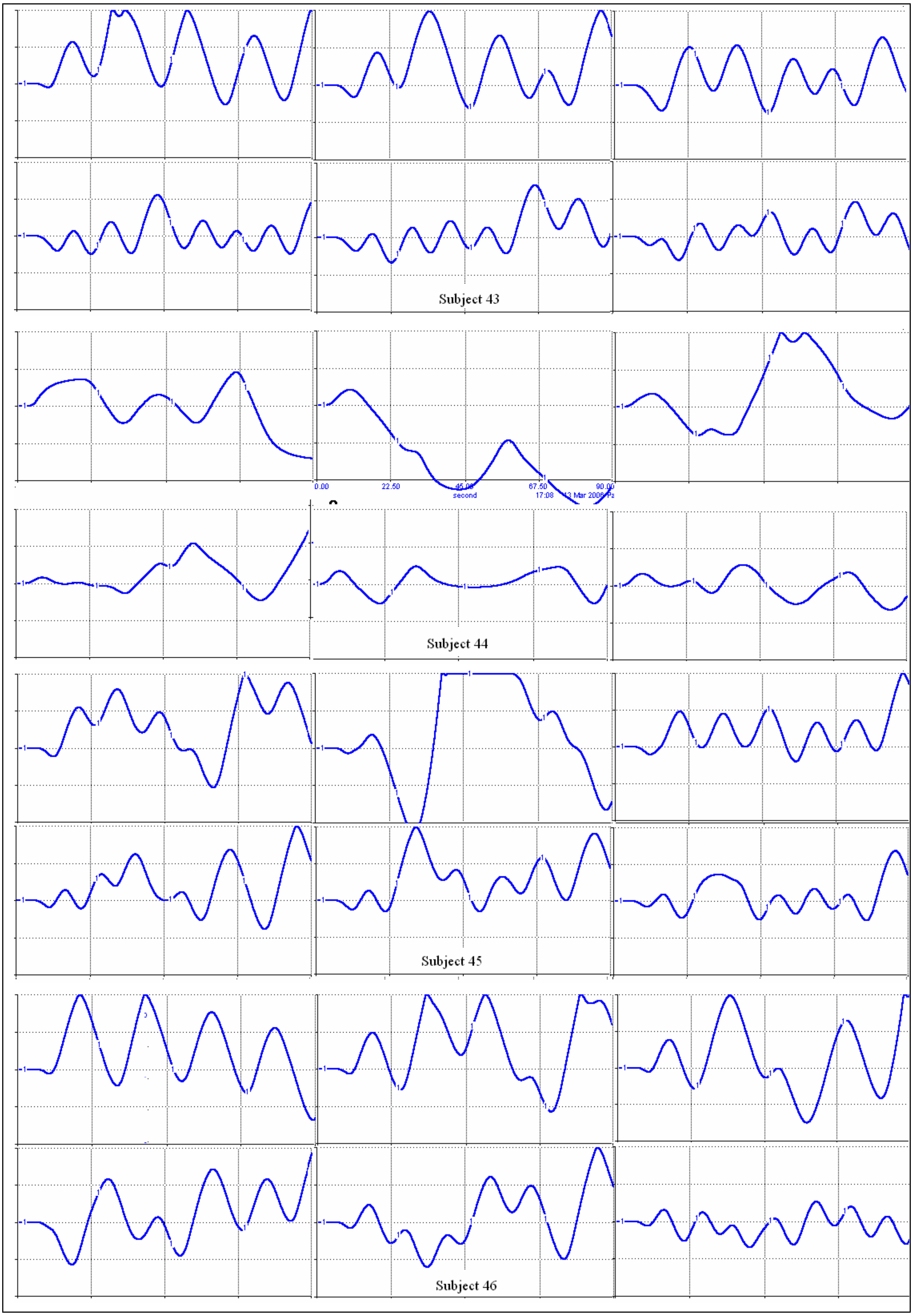



Figure F.11. Game results of Subject 43 to Subject 46

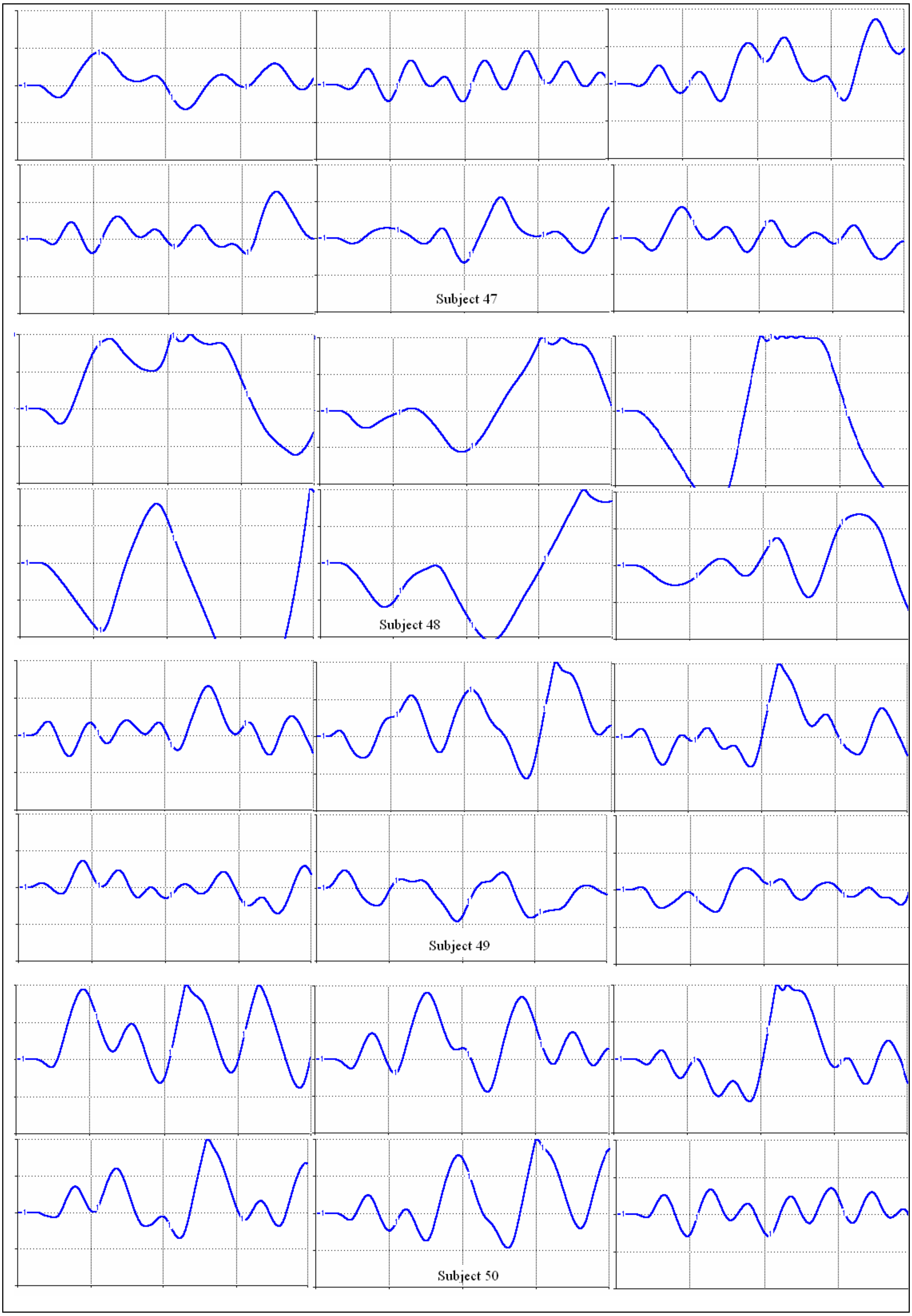



Figure F.12. Game results of Subject 47 to Subject 50

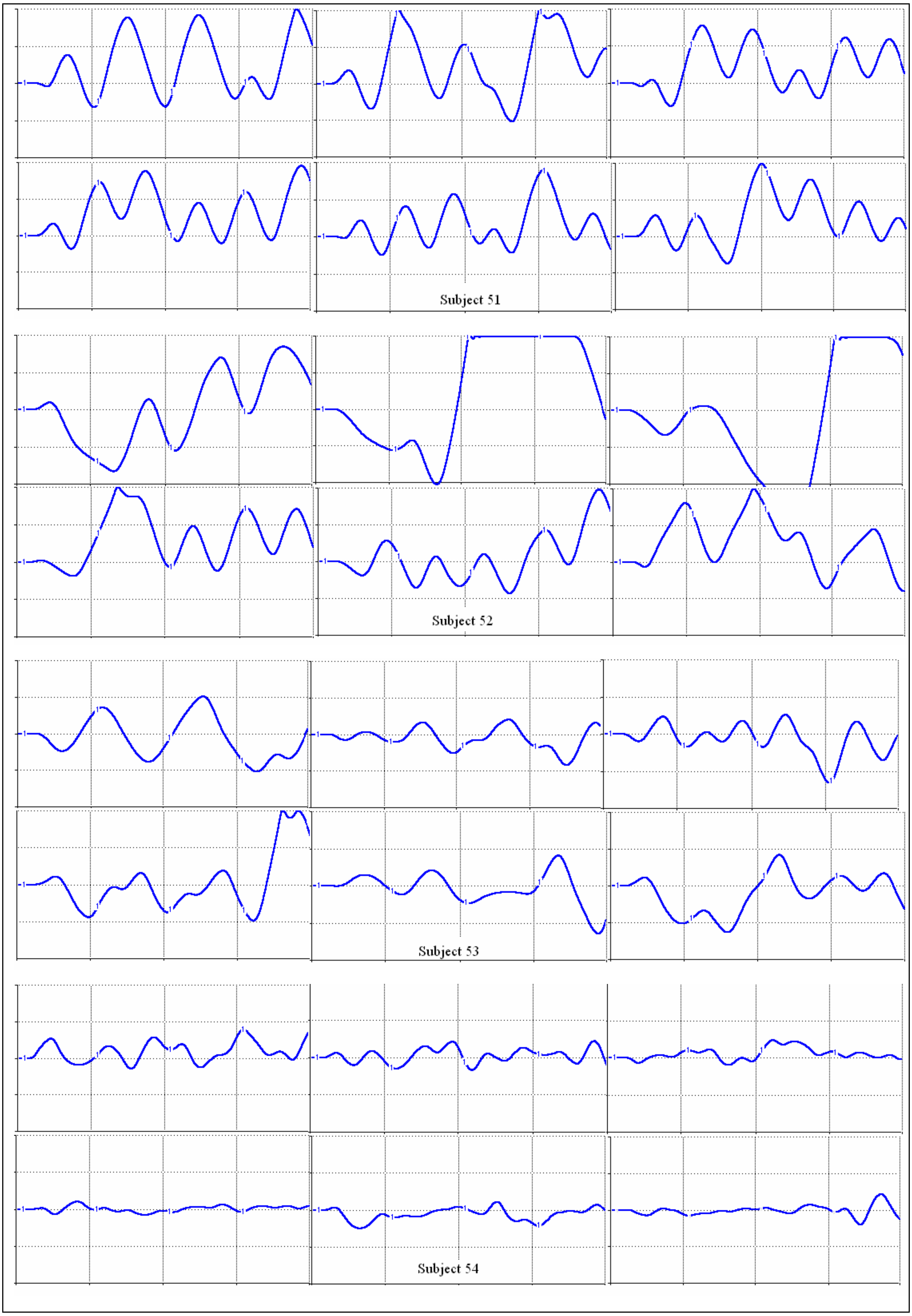



Figure F.13. Game results of Subject 51 to Subject 54

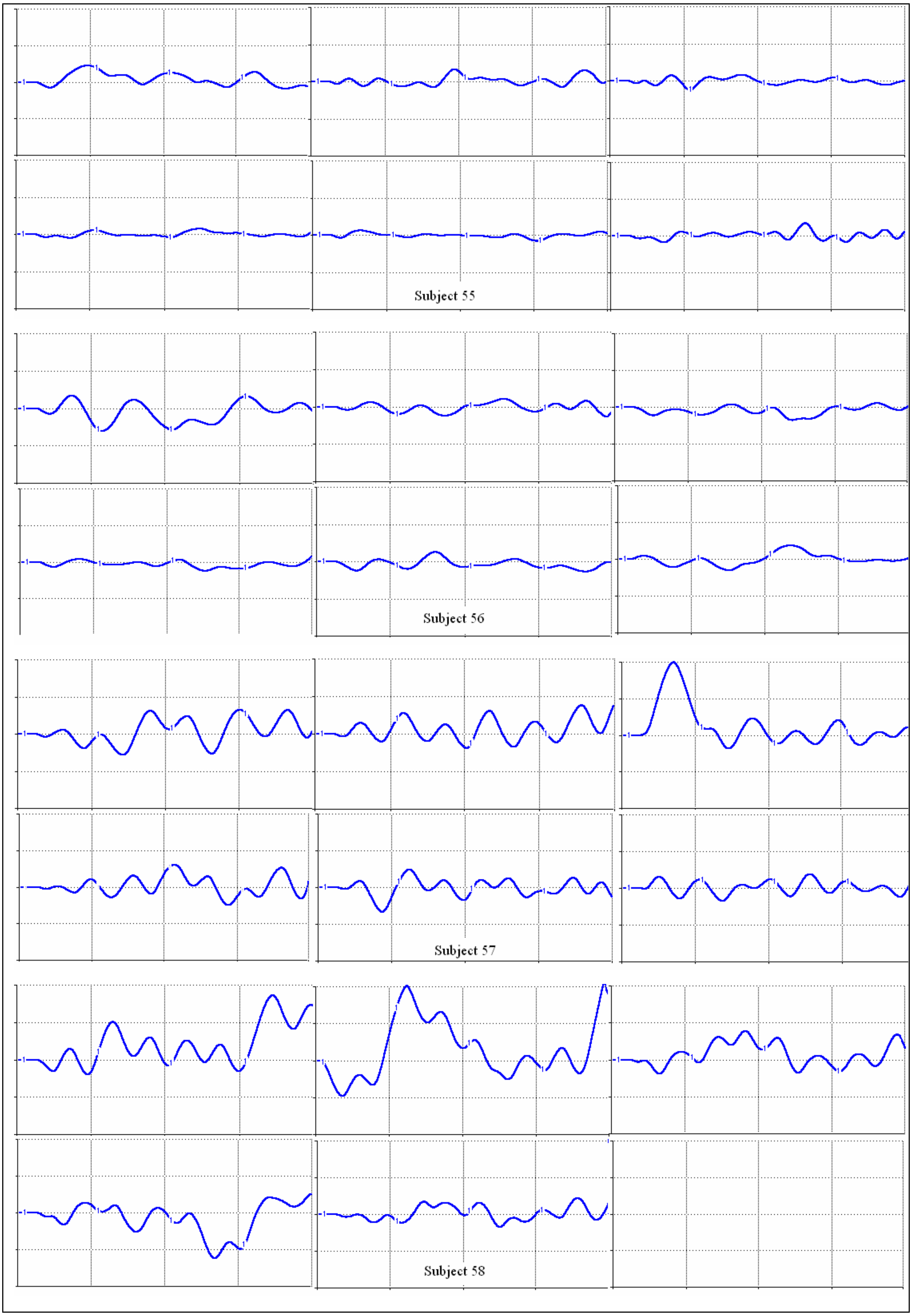



Figure F.14. Game results of Subject 55 to Subject 58

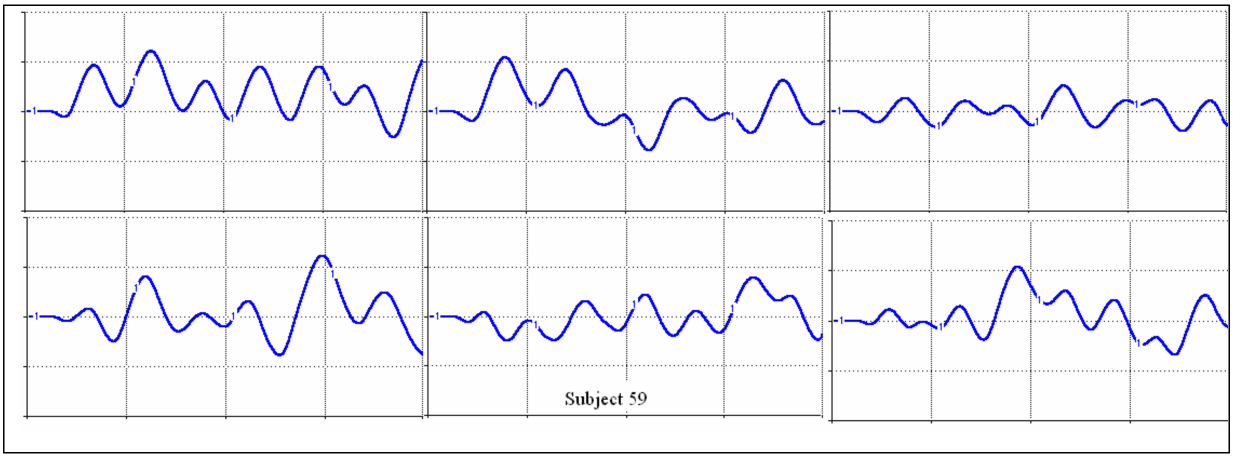



Figure F.15. Game results of Subject 59

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