Synchrony: Biometric Indication of Team Cognition

by

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ABSTRACT

The goal of this experiment is to observe the relation between synchrony and performance in 3-person teams in a simulated Army medic training environment (i.e., Monitoring Extracting and Decoding Indicators of Cognitive workload: MEDIC). The cardiac measure Interbeat-Interval (IBI) was monitored during a physically oriented, and a cognitively oriented task. IBI was measured using NIRS (Near-Infrared Spectrology), and performance was measured using a team task score during a balance board and puzzle task. Synchrony has not previously been monitored across completely different tasks in the same experiment. I hypothesize that teams with high synchrony will show high performance on both tasks. Although no significant results were discovered by the correlational analysis, a trend was revealed that suggests there is a positive relationship between synchrony and performance. This study has contributed to the literature by monitoring physiological measures in a simulated team training environment, making suggestions for future research.

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Introduction

Team Cognition among teams has been researched and described as an aggregation of individual knowledge constructs that each team member shares with each other (Klimoski & Mohammed, 1994). It has also been argued that this individual shared knowledge approach lacks the ability to capture the dynamic scenarios that teams experience (Cooke, Gorman, Myers, & Duran, 2013). Interactive Team Cognition (ITC) has strived to depart from this individualistic view of team cognition by taking an ecological perspective. This view asserts that cognition in task groups is an active process, not simply a product or property. ITC addresses the temporality associated with team cognition, whereas the shared knowledge approach does not. Also, ITC proposes that cognition should be studied at the team level. Lastly, team cognition is indivisible from the situation in which it exists (Cooke et al. 2013). Including teammates biological reactions in team research is a new field which this study will explore. Team cognition and physiological responses are rarely studied together (Elkins et al., 2009). Biometric measurement during teamwork could influence how teams are observed, trained, and critiqued. If we can understand biological processes across teammates, we can possibly begin to positively influence performance. If we comprehend the team settings and contexts in which synchrony exists, we can further understand how and why it is relevant. This study attempts to achieve this goal and to contribute to the already established literature on whether synchrony exists.

Defining Synchrony – What is Synchrony?

In the literature, synchrony is broadly defined. Synchrony is called a coincidental, procedural, or a continuous standardized temporal relation between two or more activities, which blend into a single formation (Feldman, 2007). Synchrony has also been referred to as physical compliance (PC) (Elkins et al. 2009), which is defined as "the correlation between physiological measures of team members over time."

Why is Synchrony important?

Scientists have observed synchrony over time in real-world transactions for many years (Schmidt, Morr, Fitzpatrick, & Richardson, 2012). This type of examination provides a window into the biology of teamwork. At the least, it is an intriguing phenomenon that people's bodies begin to synchronize while they are cooperating. Maybe there is a simple explanation for this happening. Possibly, if people are behaving similarly their bodies simply fall in line. However, there certainly is great variation across individuals, so there are likely additional factors in play. There are many differences between humans which could cause IBI fluctuate (e.g., age, gender, fitness level, etc.). However, teammates still subconsciously synchronize during increased performance (Stevens et al. 2013; Henning et al. 2001; Monster, Hakonsson, Eskildsen, & Wallot, 2016). This does not mean that synchrony is the end game solution to understanding team performance or that it causes improved performance; however, it may be a unique characteristic in the process of teamwork to be researched further.

The study of synchrony has always been concerned with identifying standardized patterns of synergy across individuals in interactional settings. These patterns are typically measured by behavioral, neurological, and physiological indicators. In the following sections, I review some of the literature that has been established in these domains.

Behavior has been a traditional variable in the study of synchrony. Condon and Ogston (1966) observed through film analysis that co-performers begin to synchronize physical movements over time. Many researchers have found that posture sharing may be an indicator of rapport being established; however, many postural synchrony studies have had great limitations, such as a lack of interactions, replication, and reliable measures of rapport (LaFrance, 1979). Synchrony has been examined in speaking and listening. As reviewed by Shockley (2003), talkers have been found to merge in speaking rate (Street, 1984), vocal intensity (Natale, 1975), and pausing prevalence (Cappella & Panalp, 1981). Papp, Pendry, Simon, and Adam (2013) found that married couples exhibit corresponding cortisol levels, especially for couples who spent more time together throughout the experiment. They measured cortisol levels by salivary swabbing seven times per day on two typical weekdays. They assert that physical proximity between couples may establish synchrony. Furthermore, synchrony has been connected to the examination of parent-infant synergy and the development of self-regulation, symbols, and empathy across infancy and youth, which has involved the examination of behavior congruence, affective states, and physiological synchrony (Feldman, 2007).

Biometric Observation of Synchrony

In this section I review studies of synchrony in teams in depth to provide a more detailed overview of the current state of this field of research. For the purposes of this study, I define "team" as two or more individuals who interact to achieve the best performance on a task.

Teammates are regularly adapting their behaviors in reaction to each other. This culminates in compelling integrations of data that can be examined throughout many domains (Stevens et al. 2013). Contemporary research suggests that understanding physiological and behavioral synchrony in teams may lend insight to the internal channels of team performance (Strang, Funke, Knott, & Warm, 2011). These responses could also serve as a new platform for objective measures of teamwork to be developed and enhanced (Strang, Funke, Knott, & Warm, 2011).

Studies have previously used neurophysiological data to observe synchrony. In a study of social interaction and interbrain synchronization, Dumas, Nadel, Soussignan, Martinerie, and Garnero (2010) observed cooperating dyads through video and EEG, while they participated in mimicry of each other's hand and finger motions. They found that periods of interactional synchrony correspond with the development of a neurological harmonizing structure in the alpha-mu, beta, and gamma bands amidst the right centroparietal areas. Further, as reviewed by Dumas et al. (2010), this research supports other literature findings that coinciding neurological formations are a part of team cognitive processes (Ward, 2003; Palva, Palva, Kaila, 2005). These areas have been found to be involved in social exchanges, anticipation, and governance of task switching and taking turns. This study has contributed to research which suggests that synchrony can be observed through monitoring the brain. Stevens et al. (2013) studied teams of submarine navigators and how they neurologically organize around shifts in tasks. They observed levels of engagement from an Electroencephalography (EEG) tool. Interestingly, they found that team neurological reorganization occurred across periods of stress when teams were actively working together, during periods of communication, following controlled disruption to team processes, and less in seasoned piloting teams.

Even though vocal exchanges are a collaborative activity, conversation creation and understanding have typically been studied at the level of the individual (Stephens, Silbert, & Hasson, 2010). In a study of communication, researchers consulted fMRI to measure neurological waves between orators and listeners. The listeners received an impromptu real-life story from the speaker while inside of the fMRI machine. It was discovered that the orator's neurological activity was spatially and temporally paired with the listener's neurological reactions. Because there was usually a slight delay before pairing, it is possible there were anticipatory reactions occurring between the conversationalists as well (Stephens, Silbert, & Hasson, 2010).

Stevens, Galloway, Berka, and Sprang (2009) define synchrony as the coordinated emanation of multiple brain indicators by team members while they work together. Using electroencephalography (EEG) to measure mental workload and engagement, they observed neurophysiologic synchrony during a substance abuse problem-solving task. The simulation involved giving participants different levels of information with the goal of finding out if the target was abusing drugs. Participants ran through the simulation individually to gain a mental model of the task. Then, each was placed into one of three different roles, and worked through the task as a team. The researchers did not find anything consistent across teams involving synchrony. Therefore, they examined team synchrony on a team-by-team basis. This may be a useful technique when qualitatively investigating results from studies, which apply to real-life problems due to the uniqueness that real-world issues tend to achieve, according to the researchers.

Furthermore, studies have focused on physiological measurements to analyze synchrony. Henning et al. (2001) ran two-member teams through a collaborative computer task with the purpose of moving a square through a maze while teammates had to cooperate to control the square's actions. They measured team members' electrodermal activity, heart rates, and breathing. The completion time of the maze was predicted by coherence measures. They cross-correlated team member's IBIs, and found that higher team synchronicity brought quicker completion of the maze.

Also, skin conductance synchrony has been examined during a three-person cooperative origami task. Synchrony occurred during the task without an explicit prompt. Teams high in synchrony also scored high in team cohesion. Low team synchrony typically led teams to switch to a new behavior (Monster, Hakonsson, Eskildsen, & Wallot, 2016). Levenson and Gottman (1983) observed married couples in naturalistic interactions to examine whether marital satisfaction (or marital performance) could be measured through physiological states between spouses. Electrodermal activity, IBI, pulse transmissions, and somatic activity were measured. The study showed that 60% of the variance in marital satisfaction was connected to physiological synchronicity, whereas the rest was accounted for by an affective state measure. It is also important to acknowledge that some researchers suggest that physiological compliance naturally occurs in times of heightened social transactions (Hatfield et al., 1993). Further, Henning and Korbelak (2005) studied the link between physiological synchrony and team performance. They found that cardiac synchrony was related to fewer mistakes in a dyadic tracking task. They even suggest that biological cadence in teammates may positively influence the management of random perturbations.

It is also vital to note that synchrony in teams may not always be optimal, which is why this thesis does not make such a claim. Significantly decreased synchronization could create productive task performance in teams. As reviewed by Strang, et al. (2011), some variability within biological systems has been considered to be productive (Strang & DiDomenco, 2010; Pellecchia, Shockley, & Turvey, 2005). In a study by Strang et al. (2011), two-person teams cooperatively played a variant of Tetris, called Quadra, in which one team member controlled the rotation of the shape, while the other controlled lateral movement. It was found that IBI synchronicity was negatively related to task performance. Their explanation for this contradictory finding is that studies which examine heart beat synchronicity typically involve teammates performing similar task roles, while this task involved independent roles (i.e., a true team task). Because the tasks in the current study involve similar roles, I assert that synchrony will be positively correlated with performance. However, if role homogeneity or heterogeneity has an effect on synchronization is a legitimate research question that should be acknowledged in future studies.

Summary

A common theme throughout the range of synchrony research is that synchrony exists in interpersonal transactions. When humans interact, their bodies have a tendency to behaviorally, neurologically, or physiologically show signs of synchronization. This study addresses the physiological aspect of synchronization. This type of information cannot be accurately observed by the naked-eye. Moreover, this data can give raters another level of insight into how their teams and members are performing (e.g., teammates may exert a wide range of effort to perform the same tasks). Gaining more insight on this phenomenon through biometrics could result in more accurate observations of performance.

This study examines how synchrony relates to performance of teams of three people during a physically-oriented balance board task (i.e., Team Balance) and a cognitively oriented puzzle task (i.e., Team Jigsaw). It is hypothesized that IBI synchronicity will be related to higher performance on both of these tasks, which is supported in the review of the literature. This research is important because, to my knowledge, no literature has examined synchrony across Team Balance and Jigsaw. Synchrony is typically examined on one collaborative task, between two or three individuals (Stevens et al. 2013). Also, individual versus team conditions have been compared (Stephens, Silbert, & Hasson, 2010), or one extensive task has been designed (Stevens et al. 2013). By understanding a physically oriented and cognitively oriented task, a context is applied to synchrony and team cognition (Cooke, Gorman, Myers, & Duran, 2013). By having two different task types, a major gap is filled in the literature.

This is important because synchrony could unfold uniquely across different tasks. A fifteen second time-series data analysis is used, which has not yet been seen for IBI biometric synchrony research, and gaps of 3s (Strang et al., 2011), 10s (Levenson & Gottman, 1983), 30s (Henning, Armstead, & Ferris, 2009), and 65s (Elkins et al., 2009) have been used. The results of these IBI correlations will be correlated with team performance scores. Overall, the point of this study is to observe if there is a correlation between synchrony and performance.

Methods

Larger Study Context

This study was situated within a larger study, called "MEDIC." To apply a real-world example by using the current project, researchers are testing heart and neurological Near-Infrared Spectrology (NIRS) sensors that will eventually be used during the training of Army combat medics and possibly for other real-world teams. MEDIC is an obstacle course comprised of eight tasks (four physically oriented, and four cognitively oriented). Teams of three moved through the course together. There was a two-minute time limit for all tasks except Team Balance (three minutes). Teams ran through the course twice. All data for this experiment is from trial one only. Below, Table 1 shows the tasks listed in order. The tasks used in the analysis for my thesis are highlighted in bold text (i.e., Team Balance and Team Jigsaw.)

Table 1. Task List

Task List (P) = physical task, (C) = cognitive task
1a. Team Memory (C)
2. Team Balance (P)
3. Team 20 Questions (C)
4. Team Jigsaw (C)
5. Team Hot Potato (P)
6. Team Logic (C)
7. Team Movers (P)
1b. Team Recall (C)
8. Team Jump (P)

After pilot testing, experimenters decided through observation which tasks involved the most collaboration. Also, the contrast of having a physically-oriented and cognitively-oriented task is a unique contribution to this literature field because synchrony has yet to be examined across two separate tasks.

Now, the current study could not be considered a true examination of ITC because it lacks a validated ITC metric. However, Team Balance, a task which involved three teammates handling a square board of plywood to get a ball to roll back and forth, and Team Jigsaw, a cooperative puzzle task both required communication and coordination between teammates, which are the types of interactions which create team cognition (Cooke, Salas, Keikel, & Bell, 2004). Therefore, this study is using biometrics during tasks in which team cognition is developing, which is an understudied gap, according to my review.

Team performance is also being observed during the capturing of physiological data, which is an understudied research field (Elkins et al., 2009). Researchers have been striving for many years to connect heartbeat signals to performance, fatigue, stress, and workload (Sharma, 2006). The physiological measure in this study is a cardiac metric known as Interbeat-Interval (IBI). This measure was used because of its direct relationship to the physiological system and stress (Elkins et al., 2009; Sharma, 2006). The IBI measures of two teammates were correlated over time to yield a synchrony score.

NIRS sensors will be placed on medics in training, which will provide the raters of medics in training with another level of insight to the physiological state of their trainees. This is relevant because a medic who appears cool, calm, and collected actually may be highly stressed, and *vice versa*. Medics who score sufficiently in training conversely may not perform well on the battlefield. This type of information is very difficult to observe with the naked eye or elicit by questionnaire. The information discovered by these sensors would seek to place the most effective medics out on the battlefield, which could prevent failures and save lives.

Participants

Initially, participants were recruited by public flyers, online advertisements, and by word of mouth. I recruited 21 total teams of three. However, one team did not complete the course due to a minor injury, two teams failed to show up at the designated time, and four were not included due to software malfunctions or sensor failures. Therefore, 14 teams were included in data analysis. Participants were paid ten dollars per hour ($20.00 total) for a two-hour session. If a participant arrived at the study, but their teammates failed to show, they were given ten dollars and released from the experiment. Participants who were included in this study were at least eighteen years of age, and fluent speakers in the English language. All participants had average to above average natural or corrected eyesight and hearing, and were untroubled by interacting with a team. All subjects also had the physical ability to perform lifting, balance, and puzzle exercises.

Procedure

Upon the three participants' arrival, they were seated in a room separate from the obstacle course which acted as the consenting and debriefing room. The participants typically arrived individually. Once all participants arrived, we brought them into the course room and gave them a five-minute high level overview of the course. Participants were asked if they were confident they would be able to complete all of the tasks. This was done to create understanding of and comfort in anticipating the different tasks. Then, experimenters transported the participants back across the hall to the consenting room and an informed consent procedure was administered. This involved a research assistant reading the consent form aloud, while participants followed along silently.

Once consented, the participants were then further informed about the Plux and BIOPAC sensors (see Appendix for pictures). This experiment used three Plux armband sensors, three Plux head sensors, and two BIOPAC sensors. The BIOPAC data were not used in the analysis of this study. The participant who arrived first had the number "1" armband and headband placed on them, and they were marked in the experiment as participant number "1." The participant who arrived second was dubbed participant number "2," and was strapped with Plux armband and head sensors, and BIOPAC sensor, which were all labeled number "2". The third arriving participant had the same three types of sensors put on them, and named participant number "3." Once all participants were fully equipped, the experiment began. This format of sensor application was consistent, except for Team 21, when headband 4 was used in substitute for headband 2 due to a software issue.

After completion of the study, participants were debriefed and completed a certification that acknowledged their payment for successfully completing the study. Lastly, a questionnaire was distributed to gain individual demographic information.

Tasks

Nearly any activity in life requires physical and cognitive processes. Any task could demand physical and cognitive resources. Simply existing requires these resources depending on how one defines physical and cognitive. For this experiment, these tasks are defined operationally and in comparison to each other. "Physical" is operationally defined as a task that requires strenuous bodily activity and effort, such as arm movement, leg movement, back movement, chest movement, etc. These are all movements that are required by the physically-oriented Team Balance task used in this experiment. "Cognitive" is operationally defined as a task that challenges more neurologically-oriented processes, such as abstract thinking, rationalization, logical reasoning, etc. These are all processes team members would need to use to collaboratively complete Team Jigsaw, which is the cognitively oriented task in this experiment. Once again, both tasks require these two types of processes. The research field of synchrony must begin to address different types of tasks which can be applicable to the extraordinary amount of real-world contexts in which synchrony may occur. This experiment addresses the specific context of observing medics in training through physiological biometric observation. However, this experiment could be applied to many domains of teamwork.

Team Balance. Team members stood around the four edges of a 4'x4' slab of plywood. The plywood had a runway with a width of 16" drawn down the middle and 5" end zones on each side, much like a football field. The board had 20lbs. of chains connected to the bottom of the board with clamps to add physical strenuousness to the task. To begin the task, a ping pong ball was placed in the center of the runway. Teams had to tilt the board to enable the ball to roll to each side with the objective of getting the ball into each end zone in an alternating fashion. If the ball traveled outside of the inbounds area, the team had to start their streak over from zero. Participants were free to choose and strategize how they stood around the board as long as their hands were not in the scoring zone. Participants could not use their bodies to block the ball. The scoring goal was to achieve the highest streak possible.

Team Jigsaw. For this task, participants were seated on the ground in the cognitive workspace. They were informed that they had two minutes to complete the task. The puzzle was 48 pieces in total. As a team, their goal was to correctly assemble as many puzzle pieces as possible. Their score was based on how many pieces were correctly assembled at the end of the two-minute time period. Puzzle pieces were shuffled after each trial to ensure randomness.

Following the table, Team Balance and Team Jigsaw will be described in detail because they are the tasks that have been analyzed. The exact directions which were given for each task and pictures of the tasks can be found in the protocol section of the Appendix.

Task Performance. Performance was based on a total score for each task. For Team Balance, the highest streak maintained during the task accounted for the score. A "streak" was obtained by successfully using the board to roll the ball back and forth while keeping it within the boundaries. A streak was broken if the ball traveled out of bounds, touched a participant's hand or body, or fell off the board. For Team Jigsaw, the score was based on total pieces assembled correctly. Puzzle pieces did not have to be all together in the same group. For example, if a team had five correctly assembled pieces in one spot, and two assembled pieces in a different spot, this would tally a score of seven.

Materials

There are multiple noninvasive measurements taken by the Plux Near-Infrared Spectroscopy (NIRS) In-Helmet Device and NIRS Body Band. The measurements that were taken are IBI, average Beats Per Minute, body temperature, percent blood oxygenation, standard deviation of percent bloody oxygenation, and standard deviation of heart rate. There was also a magnetometer and accelerometer in the NIRS Body Band only. The sensors are a multimodal sensors suite, which consists of multiple unobtrusive sensors which could be used on a real-world battlefield. They were designed to be durable, and resistant to motion in order to gather the cleanest data possible. Below there is a review of some neurological and physiological measurement techniques and describe the type of information the sensors record in the following paragraphs.

fNIRS In-Helmet Device. This sensor was developed to monitor neurophysiological processes of medics in training. The funders of this project are interested in assessing cognitive workload and stress levels in trainees and it has been found that when individuals enter a heightened state of cognitive workload, the blood flow to their prefrontal cortex increases (Bunce et al., 2011). As reviewed by Ayaz et al., (2010), neuroimaging techniques such as functional Magnetic Resonance Imaging (fMRI), positron emission tomography (PET), and Magnetoencephalography (MEG) have significantly enabled researchers to observe localized neurological activity.

Unfortunately, these techniques are costly, and highly sensitive to motion. For this study, NIRS is used to monitor physiological processes. This is a safe, convenient, cost-efficient, and lightweight technology that uses light to measure brain and heart activity (Ayaz et al., 2010). The In-Helmet Device uses an LED transmitter and detects reflected light it once it returns from the prefrontal cortex. The monitor was consistently placed on each participant's lower forehead above the right eyebrow, and then stretchy tape was wrapped around the participant's head to secure the sensor.

Researchers have used fNIRS to measure mental workload of Air Traffic Controllers while they handled typical and perturbed scenarios and completed a working memory and attention task. They discovered that as task complication increased, accuracy and speed of the participants decreased, while blood oxygenation increased (Ayaz et al., 2010). To my knowledge, this will be the first time NIRS is used in the measurement of synchrony.

NIRS Body Band. Because of the physical nature of training protocol for medics, a physiobehavioral sensor was developed to accompany the assessment of mental workload. The body band is similar to the helmet sensor, in the sense that it uses LED, and has an accelerometer, but it also includes a galvanic skin response sensor, and a non-contact skin temperature sensor. On both sensors, the LED was used to monitor IBI. For consistency, the sensor was strapped securely around participant's non-dominant arm.

Measures

Interbeat-Interval (IBI). The physiological measure is IBI. IBI synchrony in team members has been found to be positively related to performance (Henning et al., 2001; Henning & Korbelak, 2005; Elkins et al., 2009), which is why I used it in this study. It was also the best measurement the NIRS sensors recorded for the study of synchrony. I examine the relation between IBI synchrony and performance. In order to understand this relationship, biometrics will be correlated across two participants.

IBI is the amount of time between consecutive heart beats (Saul et al., 2007). IBI was recorded by the NIRS headband and body band. These devices project LED into the body and record the transmissions once they reflect back. Then, all data were cleaned further by manual examination in Microsoft Excel. First, the data for all three teammates for Team Balance and Team Jigsaw were extracted from a larger pool which included data from every task. Once selected, data from all three teammates were examined manually by creating line graphs in Excel. This technique made it obvious whether or not sensors had timed out at any point. Fortunately, for most teams there was at least one good sensor per each of two teammates. This strategy was adopted from Elkins et al., (2009), in a study in which researchers had similar issues. Lastly, the sensor with the best data was chosen for each teammate because each teammate had two sensors.

Analysis

The goal of this study was to determine whether synchrony is related to task performance. It was hypothesized that synchrony would be positively correlated with task performance across both tasks. In order to address the research question and prediction in the data analysis, synchrony and task performance correlations were obtained for each team. All data analyses were conducted and analyzed in Microsoft Excel. The significance of the correlations were determined by Vassarstats.net descriptive statistics calculators.

Initially, IBI measurements were received by the sensors at approximately 1.5 second intervals. However, the moment in which measurements were received across sensors (i.e., teammates) was not exact. Therefore, a 15s time-series analysis was used to time-sync the data. This means that all data were grouped into 15s time blocks from the first data point of the task to the last. For example, there may have been seven data points in a time block, and eight in another, and so on. Once all data were grouped into their respective bracket, the mean IBI was extracted for each 15s time block. This produced a total of twelve data points for Team Balance and eight for Team Jigsaw. This mean IBI extraction strategy was adopted from Elkins et al., (2009). Once IBI means were extracted for each 15s interval for each teammate, the time-synced means were assembled in chronological order and correlated. This calculation provided the final synchrony score for each team. Because the data points which were averaged within the time-series were not recorded at precisely the exact same moment, the smaller the gap, the more those differences show.

At this point, both synchrony score and task performance were registered for the fourteen teams (i.e., two out of three teammates). These performance scores were then paired with their corresponding synchrony scores in Excel, and a correlation was calculated. A correlational analysis was used to show the strength of the relationship between task performance and synchrony. Correlations were computed for each trial between each teammate. The results of these correlations will be discussed below in the Results section.

Results

For Team Balance, no statistically significant correlation was discovered between synchrony and task performance, $r(14) = .280$, $t = 1.012$, $df=12$, $p > .05$. For Team Jigsaw Puzzle, no statistically significant relationship was found between synchrony and task performance, $r(14) = .212$, $t = .752$, $df=12$, $p > .05$. Unfortunately, this may have been due to the low number of teams in the study. Below, Figures 1 and 2 depict the data for these two tasks.

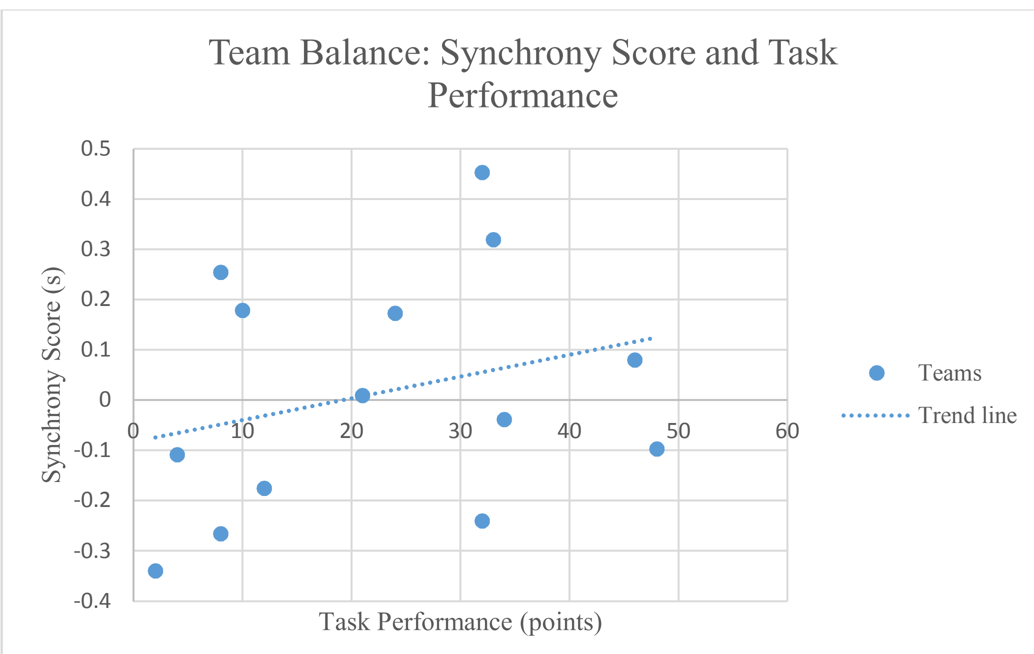

Figure 1. Team Balance: Synchrony Score and Task Performance

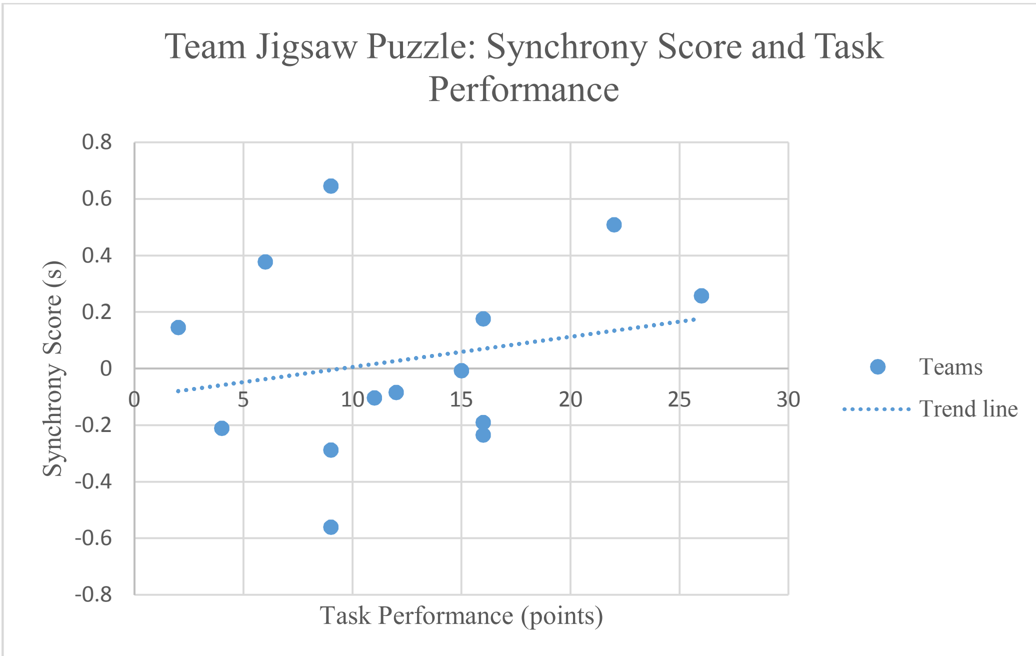

Figure 2. Team Jigsaw Puzzle: Synchrony Score and Task Performance

Implications

Because the trend line shows a slight positive relationship between synchrony and task performance the results were further analyzed to see if any qualitative patterns existed. Teams were placed into a high/low median split (Garcia, MacDonald, & Archer, 2015). Teams are referred to as high synchronous and high performing if they scored above the median, and low synchronous and low performing were at or below the median. In Table 3, teams are placed in their respective quadrant (i.e., High Synchrony/High Performance, High Synchrony/Low Performance, Low Synchrony/Low Performance, Low Synchrony/High Performance). Lastly, the teams were observed to see if any patterns remained consistent across both tasks.

The mean synchrony score for the Team Balance task was 0.014, with a standard deviation of 0.23. The mean task score was 22.43, with a standard deviation of 14.83. The median synchrony score was -0.039, the median task performance was 34.

Table 2: Team Balance: High/Low Synchrony and Performance Split

Team Balance	High Synchrony	Low Synchrony
High Performance	12, 15, 17, 8, 5	9, 16, 7
Low Performance	11, 18	14, 13, 21, 6

Overall, for Team Balance, nine teams total were either High Synchrony/High Performance (5) or Low Synchrony/Low Performance (4), while five teams total showed either High Synchrony/Low Performance (2) or Low Synchrony/High Performance (3).

Therefore, a combined nine out of fourteen teams were High Synchrony/High Performance or Low Synchrony/Low Performance. This majority aligns with the prediction of the hypothesis. However, these results are not significant.

For Team Jigsaw, the average synchrony score was 0.031, with a standard deviation of 0.32. The average task score was 12.36 assembled pieces, with a standard deviation of 6.43. The median synchrony score was -0.083 and the median performance was 11. In Table 3, teams are divided into one of four quadrants based on whether they fell above or below the median for synchrony and performance scores. The results are described below.

Table 3. Team Jigsaw: High/Low Synchrony and Performance Split

Team Jigsaw	High Synchrony	Low Synchrony
High Performance	15, 14, 8, 5	11, 17
Low Performance	12, 13, 16, 21	7, 6, 18, 9

For Team Jigsaw, eight teams were either High Synchrony/High Performance (4) or Low Synchrony/Low Performance (4), while six teams total showed either High Synchrony/Low Performance (4) or Low Synchrony/High Performance (2). Therefore, a total of eight out of fourteen teams agreed with the hypothesis. However, these results are not significant.

In summary, there is an overarching pattern which suggests that synchrony may be positively related to performance. However, this cannot be stated with certainty because of the lack of significance in the findings. Potentially, with more data, a great window of opportunity exists for a sincere pattern to be discovered.

In conclusion, the pattern of results, though not significant suggest a possible positive relation between synchrony and task performance. The overarching pattern of both tasks suggests that synchrony may be positively related to performance. It is possible that the uniquely different task contexts had an effect on these results. For cognitively oriented tasks, it may be more beneficial to use a neurological measurement, such as EEG. Once again, there is likely not a direct relationship between synchrony and performance. But it is possible a relation between the two exists.

Limitations and Future Directions

A challenge in studying synchrony is the need to perfectly harmonize the data between two or more different sources. Because our data were not recorded at precisely the same moment, a 15-second time-series was used to align the biometric information. Although using a time-series is a well-known and represented method within the literature, there is still an underlying issue in using it: the data are not actually perfectly synced in time. In the future, methods should attempt to record data at the exact same moments across the experiment, which will eliminate or reduce this limitation.

In this study, task performance was the performance variable. This is more of an outcome measure than a true performance measure. It does not provide great insight to how the team performed throughout the tasks. It simply shows the team's final score. Two high performing teams may have, in fact, have performed much differently. One team may have been excellent for a short period of time, while another kept a consistent pace throughout the tasks. Unfortunately, task performance alone does not reveal this type of information. In the future, synchrony studies should measure a team's interactions and performance as tasks unfold. Tasks could be videotaped and then later coded to see at what points in time teams were scoring or not. Then, there would be multiple tasks scores to correlate to multiple synchrony scores throughout the course of the tasks. Then, researchers will be able to see how synchrony interacts with these scores across the duration of the task. Possibly, synchrony could be more dynamic than the analysis of the current study showed.

This experiment examined IBI synchronicity. As discussed in the review, there are many avenues for synchrony to be observed including behavioral (Feldman, 2007), neurological (Stevens, Galloway, Berka, & Sprang, 2009), and other forms of physiological (Henning et al., 2001) measures. In order to yield more information from a study, it would be useful to attempt to gain more than one of these measurements throughout experimentation. Then, dimensions of synchrony could be compared with each other. Possibly, a team may be in cadence physiologically, but not neurologically. It is possible different task types (e.g., physically oriented and cognitively oriented) may produce unique effects across different data sources of synchrony. This type of cross-examination may provide a deeper insight into team cognition. It is possible that different types of synchrony uniquely relate to context. This could eventually be applied to real-life scenarios, in which teams work on either physically or cognitively demanding tasks. This study succeeded at manipulating context, but only measured one potential route for synchrony.

By the same tone, it would be valuable to incorporate well-known team cognition performance metrics into synchrony experiments. Gorman and colleagues (2016) used a team communication analysis in collaboration with neurological synchrony measurements. This enables greater understanding of team processes within the same experiment. It is possible that team communication and coordination patterns may coincide with synchrony adaptations. Then, changes could be facilitated at one level to observe if the other level reacts to it. Through the analysis of synchrony and adding established team performance metrics, the theory is further brought up to the level of the team and teams should be analyzed at the team-level (Cooke, Gorman, Myers, & Duran, 2013).

In regards to experimental design, the tasks were fairly short in duration. For future studies, 10-minute tasks or longer may provide for a more fertile environment for synchrony to develop and change. This way, there will be more data to analyze across a greater amount of time. This provides the chance for more patterns to be observed. However, in real-life teams, such as combat medic teams, new tasks can present themselves at a fast pace. Therefore, this experiment was a good example of a fast-paced, changing environment.

Also, the eight tasks of the overarching experiment always stayed in the same order. It would have been too difficult to change the experiment order from study to study. Throughout the experiment, objects had to be moved in and out of designated spaces as the participants ran through. There was a system that was developed so that this process went smoothly. Unfortunately, it is possible that the tasks which preceded the tasks which were used for analysis could have had an impact on the physical or cognitive state of the participants. However, this is unlikely due to the fact that there was about a minute pause between tasks.

Lastly, studies need to include teams of more than two people. In the real-world, teams are often comprised of more than two people. It would be interesting to examine synchrony across a multidimensional team (e.g., military command and control). This experiment involved three people, but the analysis had to be adapted due to failed sensors. This is a problem when dealing with biometrics. Sensors and software are often in developmental stages, but this study does contribute to making these types of technologies more efficient. Throughout the experiment, there was direct feedback given from user to developer.

For future studies, it will be important to continue to manipulate the context of the task. It will also be important to design experiments which provide a greater chance for significant results to be discovered. The limitations of this study and directions for future research will be discussed in detail in the next section.

Conclusion

Although this study did not reveal any expected results, it has furthered the line of research between team cognition, synchrony, and biometrics, which Stevens et al., (2013) and Gorman et al., (2016) established. Multidimensional experiments across research domains are important because they encompass many theories which can be applied to real-life endeavors. It would be appropriate to use this study as a precursor for future studies. With an upgraded methodology and data analysis, there is the potential for significant results to be revealed.

Furthermore, knowledge has been acquired about how to improve methodological characteristics of synchrony studies. It would be valuable to have longer tasks, and more performance measures. This will potentially enable synchrony to develop over a greater period of time. Synchrony adaptations could also be connected to increases or decreases in performance. Moreover, synchronization was examined across two completely separate tasks. This has not been accomplished in a synchrony experiment. Task context will begin to be manipulated in the study of synchrony. In regards to data analysis, a contribution was made by analyzing the data in a fifteen second time-series. Which had not been done to this point for IBI synchrony research.

Synchrony is a useful metric to add to the understanding of team performance and should be further inspected in future studies so more information is gained about the phenomenon. This theory has the potential to improve the assessment of team cognition and teamwork in real-world environments. The development of this research could also improve a trainer's ability to observe trainees, or in other circumstances involving team observation (e.g., hospitals, command and control, and human-robot interaction). Trainers and researchers will be able view teamwork through an internal, biological lens. This real-time assessment of teamwork is invaluable. It should be complemented by other validated, real-time team cognition, performance, and communication metrics, such as those used by Cooke, Gorman, Keikel, Foltz, & Martin, (2005).

The connection and integration of team cognition, synchrony, and biometrics may potentially have great influence on the scientific literature, and real-world team scenarios. These domains should continue to be meshed until a stronger thread of literature emerges. There is opportunity for groundbreaking research to be conducted. The combination of these fields could reveal more about monitoring performance, measuring and analyzing synchrony, and team cognition and performance.

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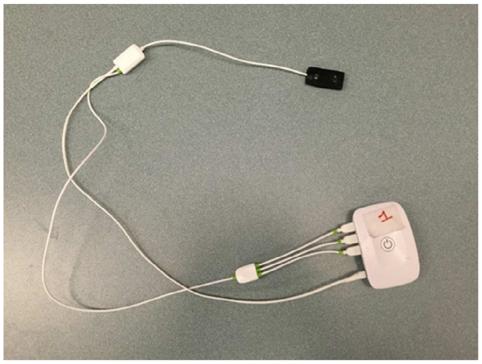
APPENDIX A

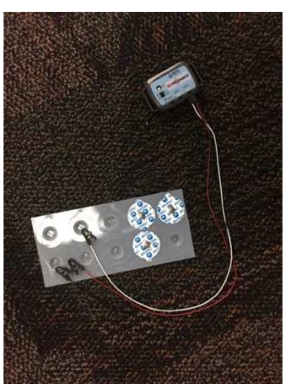
DATA COLLECTED MARCH-MAY 2016

fNIRS In-Helmet Device



NIRS Body Band

BIOPAC



APPENDIX B

DATA COLLECTED MARCH-MAY 2016

Consent Form – Teamwork

INTRODUCTION

The purposes of this form are to provide you (as a prospective research study participant) with information that may affect your decision as to whether or not to participate in this research, and to record the consent of those who agree to be involved in the study.

You may participate in this study if you are:

- At least 18 years old
- Fluent in the English language
- Comfortable participating in team activities
- Have average or corrected to average hearing and vision
- Have the ability to undertake physical balance and lifting tasks

RESEARCHERS

Dr. Nia Amazeen, Associate Professor, Arizona State University, Psychology Department

Dr. Nancy Cooke, Professor, Arizona State University, The Polytechnic School

STUDY PURPOSE

The purpose of the research is to mimic the type of teamwork that military personnel encounter in the field. We are interested in tracking physiological changes (e.g., heart rate) that take place as you perform cognitive and physical tasks with other team members. We may measure movement and speech features (e.g., speaking time and volume but not the words themselves) to help us understand the experience of teamwork. We expect to use these data to help in real-life team training.

This study is sponsored by the Department of Defense.

DESCRIPTION OF RESEARCH STUDY

In the description you read when signing up for this study, you were asked to wear exercise clothes and gym shoes. That is so you would be comfortable performing the physical activities for this experiment.

If you participate, then we will place sensors on your head, arm, and torso, and measure your activity as you perform eight different activities. We will use an alcohol prep pad to clean the surface of your skin before we attach the sensors.

There are two categories of activities: cognitive and physical. They are all done with other team members. The goal will always be to perform as quickly and as accurately as possible.

Cognitive activities are thinking activities, in which you will solve problems, memorize a list of words, work on logic puzzles, and complete puzzles with other people. Physical activities involve doing some behavior in coordination with other people. They include jumping rope, lifting or moving objects, and balancing on surfaces placed at different heights. The maximum weight of objects and maximum height of surfaces falls well within a natural range experienced by healthy adults. You will not be asked to carry more than 10 lb. (lighter than a typical backpack) alone or 25 lb. (a medium-sized dog) with someone else or to balance on a surface that is 10 inches off of the ground (the height of each step in a staircase).

After we are done with the tasks, you will be asked to answer basic questions about your background and experience with similar tasks.

You are free to decide whether you wish to participate in this study. If you say YES, then your participation will last for no longer than 120 minutes.

The study will be held at ASU-Polytechnic campus in the ISTB3 136.

We expect that approximately 100 people will participate in this research study.

COSTS AND PAYMENTS

You will earn $20 per hour for completion of this two-hour study. If you are present at the agreed upon time and date, but cannot complete the study, then you will still earn

$10.

WITHDRAWAL PRIVILEGE

Participation in this study is completely voluntary. It is ok for you to say no. Even if you say yes now, you are free to say no later, and withdraw from the study at any time. You will still be paid for your participation.

RISKS

There is minimal risk of physical harm associated with balancing at a low height. Regardless, researchers have taken many precautions to ensure your safety. Specifically, researchers will spot you to prevent uncontrolled falls. A foam pad that is designed for absorbing impact will be placed underneath the slack line so that you may step on and off the slack line safely.

You may experience slight discomfort when the electrodes are removed from your skin. The discomfort should be the same as removing a Band-Aid.

In case of emergency, researchers will contact 911 for medical services.

COMPENSATION FOR ILLNESS OR INJURY

Funding for medical services will not be available to the participant through this study.

BENEFITS

There are no direct benefits from participating in this study. However, you may receive a better understanding of how you can control your posture and balance.

CONFIDENTIALITY

All information obtained in this study is strictly confidential. As the study sponsor, the DoD is eligible to have access to research records. The results of this research study may be used in reports, presentations, and publications, but the researchers will not identify you. In order to maintain confidentiality of your records, the researchers will use alpha-numeric codes to identify your data. No names will ever be associated with data.

VOLUNTARY CONSENT

Any questions you have concerning the research study or your participation in the study, before or after your consent, will be answered by Dr. Nia Amazeen at 480-727-7075 or Dr. Nancy Cooke at 480-727-5158.

This research has been reviewed and approved by the Social Behavioral IRB. You may talk to them at (480) 965-6788 or by email at research.integrity@asu.edu if:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research participant.
- You want to get information or provide input about this research. Your signature documents your permission to take part in this research. Signature of participant Date Printed name of participant Signature of person obtaining consent Date

Signature of Participant	Date
Printed Name of Participant	Date
Signature of Person Obtaining Consent	Date
Printed Name of person Obtaining Consent	Date

Demographic Questionnaire

Please answer the following to the best of your ability. All answers will be kept confidential and will only be reported statistically (grouped with others' responses). Please feel free to leave a question blank if you feel uncomfortable answering it.

1. What is your age?
2. What is your gender? (circle):
   a. Male
   b. Female
3. What is your current level of education (circle):
   a. Less than high school
   b. High school/GED
   c. Some college
   d. 2 year degree
   e. 4 year degree
   f. Master's
   g. Doctoral
4. If you have been or are enrolled in a post high school institution, what was or is your major?
5. Are you currently employed?
   a. Yes
   b. No
6. If you answered yes to #5, what is your job title?
7. Do you work with a team on a regular basis?
   a. Yes
   b. No
8. If you answered yes to #7, in what context do you work with a team? (Circle all that apply.)
   a. Work-related
   b. Sports
   c. Recreation
   d. Other
   e. Please specify other:
9. For each item circled in #8, please indicate how many individuals make up the team.
10. I feel like my individual contribution to the team was important.
    a. Strongly agree
    b. Slightly agree
    c. Neither agree nor disagree
    d. Slightly disagree
    e. Strongly disagree
11. Regardless of our scores, I feel like we performed well overall.
    a. Strongly agree
    b. Slightly agree

    c. Neither agree nor disagree
    d. Slightly disagree
    e. Strongly disagree
12. The procedures we employed were the most effective way to complete the tasks.
    a. Strongly agree
    b. Slightly agree
    c. Neither agree nor disagree
    d. Slightly disagree
    e. Strongly disagree
13. The way we made decisions was the best way to make decisions.
    a. Strongly agree
    b. Slightly agree
    c. Neither agree nor disagree
    d. Slightly disagree
    e. Strongly disagree
14. I did **not** like the way our team made decisions.
    a. Strongly agree
    b. Slightly agree
    c. Neither agree nor disagree
    d. Slightly disagree
    e. Strongly disagree
15. These tasks were complicated.
    a. Strongly agree
    b. Slightly agree
    c. Neither agree nor disagree
    d. Slightly disagree
    e. Strongly disagree
16. These tasks were easy.
    a. Strongly agree
    b. Slightly agree
    c. Neither agree nor disagree
    d. Slightly disagree
    e. Strongly disagree
17. These tasks were boring.
    a. Strongly agree
    b. Slightly agree
    c. Neither agree nor disagree
    d. Slightly disagree
    e. Strongly disagree

18. I enjoyed participating in this study.
    a. Strongly agree
    b. Slightly agree
    c. Neither agree nor disagree
    d. Slightly disagree
    e. Strongly disagree

Participant Certification

Object Code 7400, Participant Expenses

The purpose of this form is to document the non-compensatory nature of participant payments made to or on behalf of participants in a sponsored workshop, conference, seminar, symposia or other short- term training or information sharing activity. Participant expenses are incurred solely to fulfill the goals of a specific sponsored project. Participant expenses usually are travel costs associated with attendance at the sponsored workshop, conference, seminar, symposia or other short-term training or information sharing activity.

Participants are not required to perform any services other than attending and being engaged in the sponsored event or activity. Participants may be trainees where the participant is the primary beneficiary of the sponsored activity rather than ASU or a third party. Trainees are distinct from interns in that interns provide services to ASU or a third party and must be paid through the ASU payroll system. ASU employees who are participants also must be paid any participant stipend through the ASU payroll system. For assistance in determining what payments are required to be paid through the payroll system see http://www.asu.edu/fs/TaxDept/chart/Guideintro.html

Participant's Name: ____

Participant's SSN: ____

Stipend Amount: ____

Reimbursement Amount: ____

Is participant a US Citizen, Resident Alien, or Permanent Resident? Yes

No (If stipend amount > $100, individual must complete the Alien Data Collection Form and IRS Form 8233 if tax treaty benefits are claimed)

Certification (To be completed by an authorized departmental representative): This payment is for a stipend or expense reimbursement to a participant (who is not an ASU employee) in a sponsored project, where no services (including research related services) are required as a condition of receiving payment in connection with the sponsored activity.

Department: ____

Department Representative's Name: ________________________________

Signed: ____

Date: ____

Protocol

*************BEFORE YOU BEGIN EACH DAY AND TEAM*************

Checklist

1. BIOPAC system (MP150 × 1, RESP-R × 2, Transmitters × 2, electrodes × 100, alcohol prep pads × 100, power adapter × 1, Ethernet Cable × 1, Thunderbolt adapter × 1)
2. Plux sensors (headband sensors x 4, armband sensors x 3, hubs x 7)
3. MEDIC Microsoft Surface x 1, and stylus x 1
4. Self-adhesive bandage tape × 10
5. Clean scoring sheets are placed over butcher paper on the left side of the room
6. Clean butcher block paper is placed on the right side of the room in the Cognitive Test Area (CTA). Two long strips. One is used for memory task. One is used for logic puzzles.
7. One Dry-erase marker is placed by the scoring sheets
8. 4 pencils/pens are placed in the CTA in the folder by the butcher paper.
9. Check that cognitive test materials are the in the correct place and in good condition
    a. Puzzles × 2
    b. Enlarged Word Lists x 2
    c. Enlarged Logic Problems x 2 (16 posters total)
    d. 20 question cues/scoresheet x 25 (For experimenter use only)
10. Check for a sufficient supply of informed consent forms
11. Check that Plux hubs and BIOPAC transmitters are charged.

12. Set up 3 water bottles and label them 1, 2, & 3 corresponding to team members
13. Check that there are razors available for shaving electrode areas
14. Check that there are clothes available

**********************ONCE THE TEAM ARRIVES********************

As team members arrive, the researcher directs participants to the conference room. Verify that everyone has fitness clothing. If not, offer them the lab owned clothing. Once all registered team members have arrived, the researcher gives a brief walk through of the tasks. Then, the researcher takes the team to the conference room and reads the informed consent form aloud as participants read along. Participants are given the chance to ask questions about the consent form. Once all questions are answered, participants are asked to sign the consent form along with the researcher.

After signing consent forms, participants are led to the MEDIC lab (RM 136) where they are given a brief of description about the placement of BIOPAC and Plux sensors.

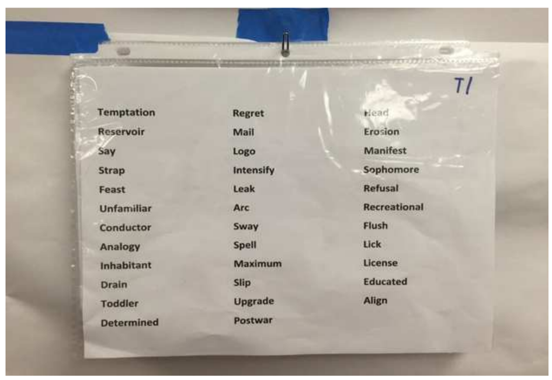
- BIOPAC – *we will place three electrodes (stickers) on your skin. One will be placed on your left side at the bottom of your ribs and two will be placed on either side of your chest just below your collar bone.*
- Plux – *we will place one armband sensor on your non-dominant arm. We will also use medical bandages to hold a sensor against your forehead*

Let the female participants know that, for their comfort, we will have a female research assistant apply the ECG electrodes. Next, show males and females to respective rooms, if necessary, to apply ECG electrodes and transmitters. Once ECG electrodes and transmitters are placed, bring everyone back to the MEDIC lab and place the Plux sensors. Once all sensors are placed, ask participants if they are ready to begin. If yes, guide them to CTA and ask them to be seated to begin the baseline measurement period. Note in both the Annotator UI and the BIOPAC Acknowledge files the beginning of baseline. After the 4-minute baseline has concluded, the research assistants guide them to the CTA and begin the instructions for the short term memory task. Below is a picture of the CTA.

1. Cognitive Task Area (CTA)

*******************************TRIAL 1*******************************

2. Team Memory



Participants begin experiment in CTA and then given the following instructions: *Here you will be presented a list of words. You are to work as a team to memorize the list of words. You will be asked to recall the list later on in this experiment. You achieve 1 point for a correctly recalled word, if you incorrectly recall, misspell, or duplicate a word, your team will lose 1 point per infraction. You have two minutes to remember and two minutes to recall. You may not write anything down for this task. Do you have any questions? Can you repeat the directions back to me?*

The RA checks that the team is ready, once confirmed, the RA starts the two-minute timer and reveals the list to the team. Once time is up, the RA immediately removes the list from the view of the team, places it in the completed task section, and moves on to the team balance area.

3. Team Balance

Participants are taken to team balance area and then given the following instructions: *Choose and place one pair of gloves on your hands. In a moment, you will each lift one side the board you see in front of you. Your task is to score as many points as possible in 3 minutes. You score one point each time the ball crosses one of the endzones marked by these lines (point to the lines). You will also be asked, as a team, to count your points aloud. If you drop the ball or the ball goes out of bounds, you must start over* (show the team the bounds lines). *Do not place your hands in the endzone and do not use your body to block the ball from falling. We will record your longest streak of points as your score.*

The researcher asks participants to repeat instructions and once satisfactory, the RA tells the team to lift the board. The RA checks the team is ready, then starts a 3-minute timer, and places the ping pong ball on the table. The RA monitors progress to make sure scoring is accurate and quickly picks up the ball if it falls. The RA records the best streak as the score. When time is expired, the RA directs the team to put down the board, remove gloves and directs team back to the CTA

4. Team 20 Questions

After completion of team balance, the RA directs the team back to the CTA and prompts the team to sit on the floor and then read these instructions: *Now we will play a game of*

20 questions. I am thinking of a food (or animal). You all have up to 20 questions to identify the object. Only yes or no questions are permitted. If you ask a question that does not have a clear answer, I will say "pass." When you successfully ask a question, place a notecard on the ground. If you correctly guess the object, we will immediately begin a new game. The most objects you can successfully guess in the two-minute round is ten. Do you have any questions? Can you repeat the directions back to me?

Since the team is already sitting, and in the CTA. They will not have to go anywhere for the next task. The RA will place the score sheet in the completed tasks folder and grab the puzzle off of the bottom shelf of the cognitive materials section.

5. Team Jigsaw

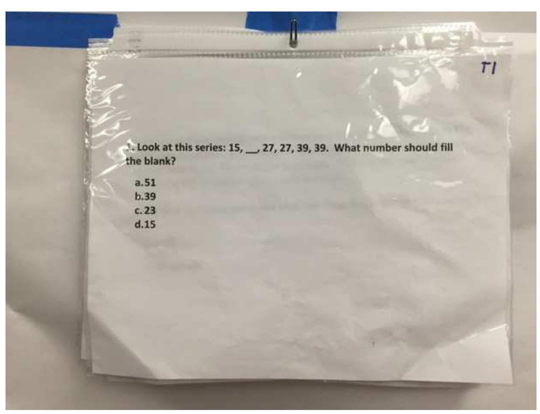
After completion of the 20 questions, the team will already be seated and prepared for the puzzle task. The researcher will prompt them with these directions: *Here you will attempt to complete a puzzle as a team. You have two minutes to complete the puzzle. Your score is based on how many pieces of the puzzle you correctly assemble. Do you have any questions? Can you repeat the directions back to me?*

At this point, puzzle pieces need to be counted for the team score and then cleaned up. It will probably be tough for the RA who is moving the team through the course to do this. Once the puzzle is scored and removed. The team will advance to the bosu ball area.

6. Team Hot Potato

After completion of the puzzle, the researcher directs the team to the bosu ball area and directs 3 of the team members (those wearing sensors) to stand on the bosu balls. Give the team a few seconds to become acquainted with sitting on the bosu balls. Once they seem like they have gotten the hang of it, the researcher gives the following instructions: *Your task is to score as many points as possible in 2 minutes. You score points by completing successfully tossing and catching this medicine ball (shows medicine ball) to you team member. You will always toss in a counter-clockwise fashion. Work as a team to count your points out loud. If you drop the ball or fall of the bosu, start over. We will record your longest streak of successes as your score.* The researcher asks participants to repeat instructions. Once satisfied the RA signals the team to begin, hands them the medicine ball and starts a 2-minute timer. The RA monitors scoring for accuracy. Once timer is expired, one RA directs team to CTA. The second RA records the team score.

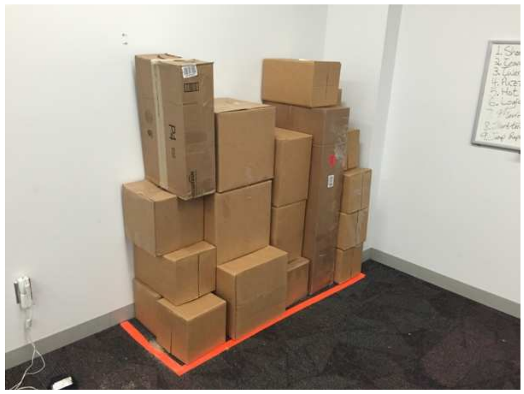
7. Team Logic



After the hot potato task, the team is directed back to the CTA. And prompted with these directions: *Here you will complete a series of logic problems. Your goal is to correctly complete as many questions as possible within the two-minute time limit. As a team, you are only allowed to work on one problem at a time. Problems will be presented individually, if you would like to skip a problem, and move to the next, simply say "skip." You are permitted to revisit questions that you initially skip. You will be scored on how* *many questions you complete correctly. Feel free to write on the work board if necessary. Do you have any questions? Can you repeat the directions back to me?*

Collect the team's answer sheet to be scored after the completion of the trial and move them to the moving boxes area.

8. Team Movers



After completion of the logic puzzles, direct the team to the moving boxes area. Once there, give the following instructions: *Your task is to work as a team to move these boxes (point to boxes) to the other side of the room. You will have 2 minutes to move the boxes. However, you must obey the following rules. You must (1) completely fill the area marked off by the orange tape without exceeding the perimeter, and (2) the boxes must be stacked in a stable way. If you deviate from these rules, we will ask you correct the mistake. We will record your score as the number of boxes stacked that meet those criteria.* As usual, ask for the team to repeat the rules. Once satisfied, start a 2-minute timer and give the signal to begin. The RAs will monitor team performance for following rules and correct when necessary. Once the timer expires, the RA records their score and directs the team to the CTA.

9. Team Recall

Upon the completion of moving boxes, the team will be directed back to the CTA and read these instructions: *Now you will recall as many words as possible from the list you* *memorized earlier. Your score will depend on how many words you can recall. You achieve 1 point for a correctly recalled word, if you incorrectly recall, misspell, or duplicate a word, your team will lose 1 point per infraction. You have two minutes to recall the list. Do you have any questions? Can you repeat the directions back to me?*

Participants will recall as many words as possible on the trial 1 work paper. *The scoring for this is probably the most time consuming of all the tasks. It will likely have to be done after the experiment. After this, the RA will instruct the participants to pick up a jump rope.

10. Team Jump

After completion of the short term memory recall period, participants are directed to one of each of the jump ropes and told to form an approximate circle when they are facing each other. Participants are instructed to try a few jumps and instructed to (and how to) adjust rope length if necessary. Once everyone is ready, participants are given the following instructions: *Your task is score as many points as possible in 2-minutes. You score points by performing synchronized rope jumps. By synchronized, we mean that each team member jumps at the same time. You will, as a team, count your jumps aloud. If any team member fails to jump at the same time, start your count over. We will record your longest jumping streak as your score.* As always, verify understanding of instructions through participant repetition. Once satisfied, give the signal to begin and start a 2-minute timer. When the timer expires, the RA records the score and directs the team back to the CTA, and either begins the next trial or moves on to debriefing.

****IMPORTANT: AT THE END OF TEAM JUMP ROPE, MAKE SURE THE BOSU BALLS AND THE TEAM BALANCE BOARD ARE BACK IN PLACE. ****

**********************************TRIAL 2****************************

After completion of the first trial, the researchers check if the team is doing OK? If they need to get water or use the rest room, allow them to do so. Once everyone is OK, show them their score and encourage them to try and beat their score and the high score if applicable. Start back over at Short Term Memory Study Period with a new set of words and work through the tasks in the same order.   Once all tasks are complete, remove all of the sensors and move on to debriefing.

**********************************DEBRIEF*************************

Thank you again for volunteering to participate. US military medical personnel may be deployed to a variety of operational environments where their success saving lives depends on their ability to act quickly and effectively, both as individuals and as teams. Therefore, effective training must go beyond individual skills to include interactions among team members, and how those interactions transfer to operational environments. Currently, trainers must infer competence by observation alone, a challenging task. Automatically sensing indicators of cognitive workload can augment performance observations, offering insight into factors underlying that performance. In this study, we are comparing a new set of sensors, those worn on the arm and head, with a more conventional form of measurement, the electrodes worn on your chest, on a range of tasks meant to emulate those experienced by medical teams in a field setting. What we learn here may improve the safety and training of the military personnel. Do you have any questions?

Pay team members and have them sign a receipt.

**********************ONCE THE TEAM LEAVES**********************

Clean all equipment, restore the room to its previous state and recheck the opening checklist.