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Training: Neural systems and intelligence applications

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Abstract

Advances in modeling and simulation can now substantially improve intelligence training. To maximize the benefit of such advanced training systems, analysts and trainees must be equipped with tools that measure, diagnose, and mediate intelligence operations training exercises. When training foraging skills, neurotechnology can be used to monitor an analyst's processing of data sources, diagnose how well relevance factors are determined and 'nuggets' are formulated, and initiate mediation when inadequacies are revealed. Neurotechnology could also be used to train sense-making skills by testing the quality and correctness of analyst decisions and facilitating the cognitive nuances inherent to individuals during the analytic sense-making process. This article discusses possible use of neurotechnology for measurement, diagnosis, and mediation in both the bottom-up and top-down processing cycles of information analysis, and provides a case study that summarizes the implementation of one such tool – the Revolutionary Advanced Processing Image Detection (RAPID) system.

Key words: Information analysis, intelligence operations training, foraging, sense-making, neurotechnology, bottom-up processing, top-down processing, Revolutionary Advanced Processing Image Detection (RAPID) system

Functional neuroimaging is progressing rapidly and is likely to produce important findings over the next two decades. For the intelligence community and the Department of Defense, two areas in which such progress could be of great interest are enhancing cognition and facilitating training.

National Research Council (1)

Introduction

Lahneman, Gansler, Steinbruner, and Wilson (2) suggested that the intelligence community (IC) will soon "… experience an imbalance between the demand for effective overall intelligence analysis and the outputs of the individually-oriented elements and outlooks of its various analytic communities." The IC is producing analysts tailored to engage specific, focused missions. There is a need to train analysts to perform in a flexible manner that is conducive to supporting both kinetic, especially asymmetric warfare, and non-kinetic operations. This need can be supported with current training technologies that enable trainees "… to practice intelligence functions at all levels of war, from unconventional, low-intensity, tactical engagements to conventional, high-intensity, force-on-force conflicts (3)." Advances in modeling and simulation can now integrate realistic, dynamic, and unpredictable virtual training environments with real-world mission data (e.g., unmanned aerial system feeds, satellite-orbit displays, etc.), and substantially improve intelligence training. While these simulated environments deliver realistic training opportunities, we posit that in order to maximize learning, senior analysts and trainees must be equipped with both tools that support the measurement of learning outcomes, and the evaluation of training effectiveness. Thus, an unmet challenge is how to best measure, diagnose, and mediate intelligence operations training exercises so as to ensure that learning is maximized. Neurotechnology could be used for, and in such assessment. Specifically, neurotechnology could be employed in both the bottom-up and top-down processing cycles of information analysis.

Training intelligence operations

In training intelligence operations, it is critical to address a variety of interrelated activities that comprise the nested top-down and bottom-up cycles through two reciprocal processes (4):

- Bottom-up processing is used to integrate series of events and data into evidence, schemas, and hypotheses that explain *how* an event occurred and/or is likely to occur in the future.
- Top-down processing seeks additional evidence to support previously created hypotheses/propositions to explain or predict why an event occurred and/or is likely to occur.

Top-down and bottom-up processes constitute the "think-loop cycle," and are mutually engaged to create and validate accurate hypotheses that are important to accurate information analysis (5). The complexity of this process is evident in the nested cycles presented in Figure 1. At the highest level, the cycle is broken down into two subprocesses with distinctly different goals, the foraging loop and the sense-making loop (4). The foraging loop gathers information. At this stage, the analyst will perform high-level searches of data repositories for information related to a specific question or topic of interest (e.g., biotechnologic capabilities of a target country). Once the information that is gathered begins to evolve into a "story," a more comprehensive analysis of the selected sources is performed to extract more detailed information to address gaps related to the question/area being evaluated. When enough snippets of information have been extracted to afford a relative understanding of a given question/area, the sense-making cycle is entered. At this stage, the analyst uses schemas to create propositions/hypotheses based on the evidence extracted during foraging. After developing hypotheses, analysis may progress to a more top-down process in order to link extracted data to support or refute the hypotheses. If at any point additional data are required to validate the evolving "story," the foraging cycle is re-entered to further gather supportive or contrary information.

Because of the high ambiguity and limited reliability of intelligence sources, and the effort of data interpretation,

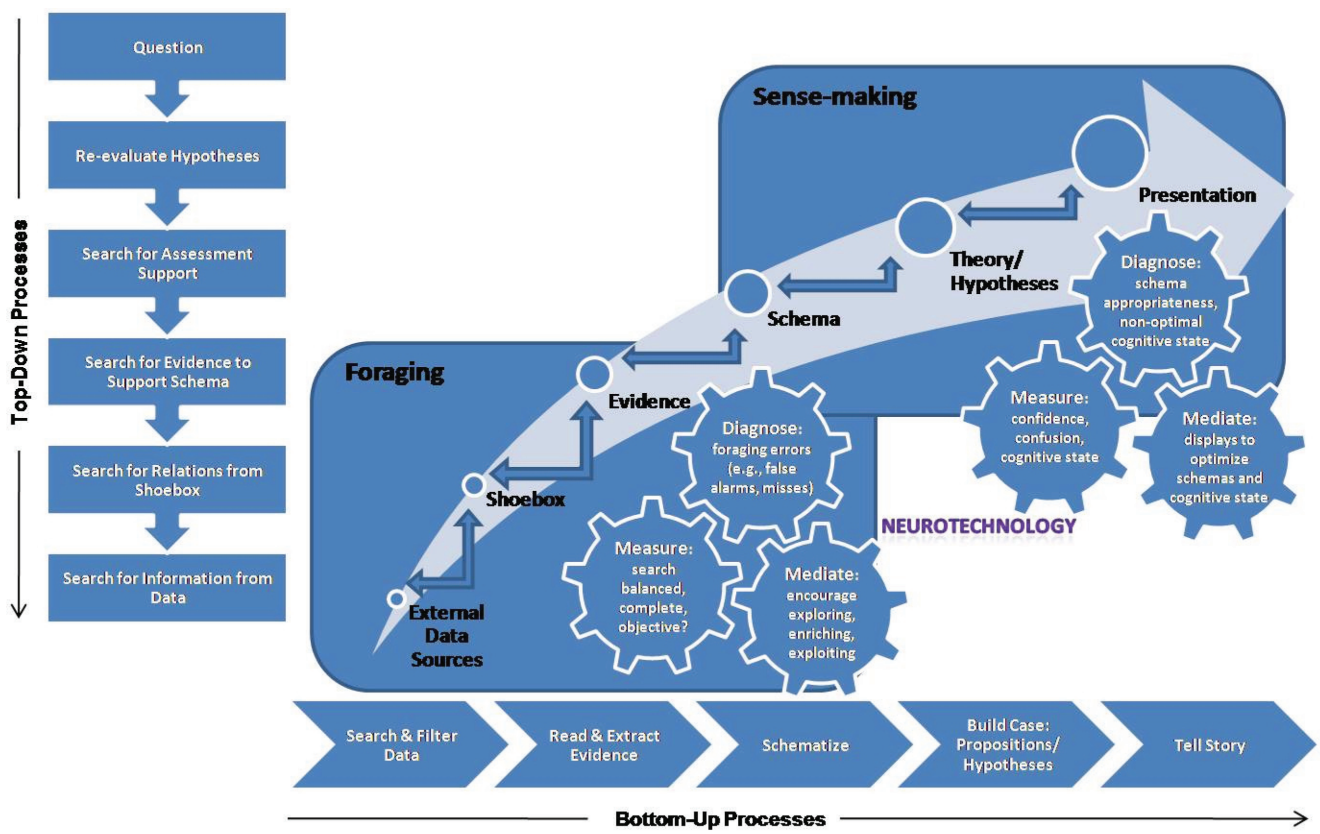

Figure 1. Neurotechnology Concepts to Support Training of the Information Analysis Process (adapted from Bodnar (5) *and Pirolli & Card* (4)*)*

analysts represent a key component in any authentic processing of intelligence sources. Therefore, it is important to effectively train and support intelligence personnel in those skills required in high level analysis. Leading-edge training techniques for intelligence operations are currently being developed that combine intensive instruction, simulated practical exercises, and maximum leveraging of emerging technologies (3). Neurotechnology is one such technique that could be used to enhance training during both the foraging and sense-making cycles.

Neurotechnology for measurement, diagnosis, and mediation of foraging skills

"While predictions about future applications of technology are always speculative, emergent neurotechnology may well help to… enhance [the] training techniques" of the intelligence community (1). Neurotechnologic implements may be highly valuable training tools to enhance the measurement, diagnosis, and mediation of foraging skills. Foraging involves bottom- up processes for searching/filtering and reading/extracting of data sources (see Figure 1). Search and filter activities focus on supporting information retrieval, which entails the bottom-up strategy of defining a 'target' (e.g., labeling a high-value individual, infiltrator, rogue element, physical system, insurgent camp, area of operation, etc.) from which to collect relevant data (4,5). The objective of read and extract activities is to support evidence accumulation as relevant to the target. Foraging also involves top-down processing when seeking information from collected data sources and searching for relations from collected information (see Figure 1). The search for relations activity focuses on reevaluating documents or information snippets that have previously been accumulated into a concept "shoebox," that is related to the current analysis goal. The objective is to seek available external data sources to more deeply assess and track new leads with regards to the working hypotheses.

The fundamental element of foraging, whether bottom-up or top-down, is the collection of 'nuggets' of evidence from relevant data sources that can be used to support sense making (5). When training foraging skills, neurotechnology can be used to monitor an analyst's processing of data sources, diagnose how well relevance factors are determined and 'nuggets' are formulated, and initiate mediation when inadequacies (of skills or outcomes) are revealed. Thus, we posit that during training of foraging skills neurotechnology could be used for:

Measurement

- Providing determinations of when and what data elements analysts are reading/viewing, and/or discarding so as to assess if the search is balanced, complete, and objective (6).
- Capturing confidence, confusion, and/or interest via neurophysiological indicators that could be associated with each evidence 'nugget' gathered to evaluate the quality of both evidence items and, ultimately, the analysis at large.

Diagnosis

- Providing identification of specific data elements that cause analysts to become more or less interested, confused, or confident and comparing the characteristics of these factors to pre-identified areas of interest (AoI).
- Supporting detection of errors (e.g., false positives, misses) during foraging that negatively impact extraction of relevant data elements.
- Detecting a narrow search, which indicates that potentially relevant information is being discarded based on top-down processing or "explaining away" data elements.

Mediation

- Providing techniques and devices to collect, highlight and/or review data elements to which analysts showed subconscious "interest" (i.e., detection of neurophysiological indicators) but did not include in analysis (e.g., because of being "explained away" by prior, and/or tacit knowledge).
- Facilitating exploration or monitoring of a broader and/or deeper information space, thereby allowing enrichment of data elements that have been collected for analysis, by creating smaller, high(er)-precision data sets, and exploiting gathered items through more thorough review (4).

Neurotechnology for measurement, diagnosis, and mediation of sense-making skills

Neurotechnology could also be used to enhance the measurement, diagnosis, and mediation of sense-making skills during training. Bottom-up sense-making involves fitting evidence into schemata (i.e., a representation from which conclusions can easily be drawn), defining hypotheses/propositions, building supporting cases, and telling the story that is depicted by the evidence (see Figure 1). The schematizing activity focuses on marshalling supporting evidence, such that the analyst can begin to build a case by assembling individual components of evidence into a simple schema (4, 5). The objective of hypothesis generation/case building activity is to support theory formulation, which synthesizes a number of interlocking schemas into a proposed theoretical construct. Storytelling activity focuses upon developing a presentation (i.e., hypotheses with supporting arguments, viz - the ideas, facts, experimental data, intelligence reports, etc. that are supportive/contrary) with which to convey and disseminate results of analyses.

Top-down sense-making involves questioning, re-evaluating hypotheses, searching for assessment support, and searching for evidence (see Figure 1). The objective of questioning activity is to re-examine the current story to identify if a new or refined theory must be considered. Re-evaluating activity seeks to explicitly state a new hypothesis to support the identification of kinds of evidence that are needed for support or refutation. Search for assessment support activity identifies and formulates available propositions that support or refute the working hypothesis, and modify or re-build existing propositions to address new hypotheses. Search for evidence activity attempts to uncover available "nuggets" of evidence within the "shoebox" that supports or refutes the working hypothesis, or seeks to identify new evidence necessary for hypothesis testing.

The essence of sense-making, whether bottom-up or top-down, is to build a story by synthesizing "nuggets" of evidence into schema and testing /refining hypotheses comprising these constructs (5). Neurotechnology could be used to train sense-making skills vital to assessing appropriateness of schemas and hypotheses, by testing the quality and correctness of analyst responses and decisions and facilitating the cognitive nuances inherent to individuals during the analytic sense-making process. Thus, we posit that candidate areas where implementation of neurotechnology could lead to substantial improvements during the training of sense-making skills include:

Measurement

- Providing techniques to capture confidence and/or confusion using neurophysiological indicators during "nugget handling" that could be associated with the appropriateness of utilized schemas (e.g., "strong" versus "weak" linkages between evidence 'nuggets' and propositions/hypotheses), and thereby identify when sense-making links are aligned with current mental models.
- Capturing the cognitive state(s) of the analyst (e.g., sensory memory, working memory, attention, executive function, etc.) via neurophysiological indicators (6).

Diagnosis

- Identifying when the cognitive state is non-optimal (e.g., working memory load is high, attention bottlenecks are being experienced, etc.), and might therefore impair sense making capacity.
- Identifying when mental models are inappropriate for assessing evidence (e.g., confusion), thereby indicating a potential bias and/or inaccurate analysis.
- Evaluating in real-time the effectiveness of information analysis as regards to timeliness (e.g., temporal fit of evidence marshaling and theory building so as to support planning, influence decisions, and prevent surprise), relevance (e.g., relevance of intelligence gathered addressing the objectives of the analysis), and accuracy (e.g., viability of intelligence gathered to provide a balanced, complete, and objective theory of the target threat, inclusive of considerations of uncertainties, as well as alternative, and/or contradictory assessments).

Mediation

- Providing mediating techniques aimed at optimizing cognitive state (e.g., offloading information patterns onto multimodal displays, such as visual mediators) (4,7).
- Providing mediating techniques that encourage reassessment of mental models/schemas when deemed no longer relevant (e.g., to highlight and encourage correction of weak evidence links).

In these ways, neurotechnology has the potential to provide objective measures in a highly subjective process, and could be used as a training tool to enhance analysis outcome(s) through measurement, diagnosis, and mediation of specific deficits in the analytic process.

Case study: Neurotechnology support of foraging during image analysis

Neurotechnologic solutions have been developed that improve the speed and quality of evidence gathering (i.e., foraging) in intelligence operations. Clearly then, such applications could be applied to training. For example, the Revolutionary Advanced Processing Image Detection (RAPID) system is designed to enhance both image throughput and analysis accuracy by incorporating neurophysiologic measurement techniques into a closed-loop that 1) tracks the imagery analysis process and 2) automatically identifies specific AoI within reviewed images (8, 9). RAPID incorporates two distinct neurophysiologic instruments, eye tracking technology, and electroencephalography event-related potentials (EEG/ERP). Eye tracking technology offers a unique method for cognitive assessment by determining exactly what a person has visually perceived. This "has become one of the most important and productive ways for investigating aspects of mind and brain across a wide variety of topic areas (10)." Further, eye tracking technology has revealed behavioral differences between novices and expert search patterns, percentage of time looking at AoI, and site fixation(s) (11).

Current EEG technology has been shown to have excellent temporal resolution and allow tracking of neural activity reflective of information flow from sensory processing to initiation of a response (i.e., of particular interest is that human EEG responses observed during target searches of rapidly viewed images reveal that perception of a specific item occurs 130-150 ms post-stimulus- and therefore before conscious recognition occurs) (12). Additional support for using neurotechnology to enhance training in decisional accuracy is provided by research that demonstrates the capacity of using EEG/ERP to differentiate between correct responses (i.e., hits and correct rejections), and highly biased responses (e.g., false alarms and misses) (13-15). In this way, application of EEG technologies, such as RAPID, could be employed during foraging to identify images that contain AoI using neural signatures, and: 1) eliminate the need for assessing behavioral responses and 2) improve the speed of image throughput. Further, the RAPID architecture allows for a natural review of images and monitors event-related EEG distinctions observed early in bottom-up processing (i.e., search and filter), which may reflect a preemptive categorization using simple features or combinations of features that allow rapid matching or mismatching to an existing template (i.e., target versus non-target) (12,16). Eye tracking data and EEG/ERPs can be synchronized to create fixation-locked event-related potentials (FLERPs) that can depict cognitive interest at each fixation point (based on signal detection theory) (8,9). As an analyst reviews an image, all fixations over a given duration threshold (17) [i] could trigger evaluation of associated EEG/ERPs to categorize the fixated area as 'of interest' (i.e., hit), "of no interest" (i.e., correct rejection), or 'misinterpreted' (i.e., false alarm or miss). Using such techniques, interest areas can be automatically extracted for further review and top-down-driven sense-making and misinterpreted locations can be tracked to identify patterns of missed AoI and/or areas of distraction. Detection of such error patterns could, in turn, trigger training mediation that engages real-time adaptive strategies to highlight and correct error patterns.

To create FLERP templates built into the RAPID system, human participant data were collected using Commercial IKONOS and Quickbird panchromatic imagery of Seoul, Korea (18). A set of 100 image tiles were presented as full-screen static images to participants throughout the test session. Within the series, 50 images (50%) contained a single helicopter pad (helipad), which served as the search target. In order to ensure that search targets were not consistently presented in a single area of the display, target stimuli were randomly positioned within each target image. AoI were pre-defined within presented images through a bounding box of approximately 100 pixels surrounding each identified target of interest for data analysis purposes (note: participants were not shown AoI).

During imagery review, both eye tracking and EEG data from nine distinct scalp locations were collected using unobtrusive measures (a desktop mounted eye tracker and non-invasive EEG sensor cap) and post-processed to classify fixations relative to ground truth AoI (i.e., fixations on AoI, and whether that area was selected by participants as "of interest"). Distinct differences in EEG patterns were shown between fixation classifications, and those were used to create classification templates that could be subsequently used for real-time comparisons during imagery review. In order to develop a single-trial classifier (i.e.- an algorithm that classifies each fixation based on the neural-signature associated with that fixation) FLERP data acquired from participants were analyzed to extract EEG variables, including fixation-locked power spectra and wavelet transformations at 0-2Hz, 2-4Hz and 4-8 Hz. To achieve near real-time classification of interest, RAPID's diagnostic engine applies Linear Discriminant Function Analysis (DFA) to pre-selected variables to compare incoming single-trial FLERPs data against predefined templates. Cross-validation of a 2-class classification model to distinguish hits from correct rejections (keyed) based on 9-channel data ranged from 76% to 96% (9, 19).

In summary, RAPID is a neurotechnology that could be used to support the measurement, diagnosis, and mediation of intelligence operations training exercises, (with particular utility in the foraging loop), as follows:

- *Measurement*: RAPID could be used to determine when, and to what visual data elements analysts are attending, and assess the appropriateness of their assessment of interest/relevance for each area reviewed (e.g., identify hits, correct rejections, false alarms, misses, areas within the image that were not visually fixated upon).
- *Diagnosis*: RAPID could be used to identify errors in foraging, such as distractive visual data elements (i.e., false alarms), and missed visual data elements (i.e., AoI that were discounted or not appropriately considered).
- *Mediation*: RAPID could be used to focus training upon observed error patterns via real-time scenario adaptation (e.g., incorporation of subsequent images that highlight missed areas) or after-action review (e.g., providing training to remediate consistently missed visual element(s) in a particular orientation or location).

RAPID could be paired with feature recognition algorithms, or ontology-based intelligent agents that are capable of identifying what is at each defined AoI to enhance the power of training effectiveness (18). Such a system could discriminate (if not "learn") what objects/entities are being correctly/incorrectly reviewed (i.e., more powerful diagnosis). This could be used to generate more targeted training feedback (i.e., mediation), which would thereby enhance imagery intelligence training effectiveness and efficiency.

Conclusions

Neurotechnology has potential to enhance intelligence analysis training, as it can provide objective measures of the highly subjective analytic process. During foraging, the identification and remediation of 1) non-optimal cognitive states (e.g., low engagement, high distraction), 2) detection of lack of critical evaluation(s), or 3) continual attentional focus on distracting data [i.e., false alarms], could be important to enhance information gathering. Furthermore, neurophysiological monitoring during the sense-making process could be employed to evaluate neural activations that subserve critical thinking tasks and skills during the collection and discrimination of information snippets. Depicting and understanding these neural patterns (i.e., diagnosis) could be important to assess error or success patterns, identify substrates of bias when formulating argument chains, and thereby depict individual neural "signatures" in task acquisition and learning. Targeting these substrates- either through cognitive, behavioral, or neurophysiological mediations, could thereby 1) personalize training, 2) shorten training times, 3) heighten training efficiency, and 4) decrease performance errors in real-world 'field' situations. Taken together, these applications of neurotechnology could lead to a level of training (i.e. increasing effectiveness of evaluation of foraging and sense-making skills) that is well beyond the capability of current techniques.

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Disclaimer

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Competing interests

The authors declare that they have no competing interests.

Notes

i. Graf and Kruger (1989) have proposed that short fixations (<240 ms) and long fixations (>320 ms) be classified as involuntary and voluntary fixations, respectively.

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