September 1, 2015

Operator-Centered Task Analysis: A Hybrid Methodology for Human-Machine Interaction Observation in the Field

Chase Meusel, *Iowa State University*
Norene Kelly, *Iowa State University*
Stephen B. Gilbert, *Iowa State University*
Michael C. Dorneich, *Iowa State University*
Brian Gilmore, *Deere & Company*, et al.

Operator-Centered Task Analysis: A hybrid methodology for human-machine interaction observation in the field

Chase Meusel, M.S., Iowa State University
Norene Kelly, M.S., Iowa State University
Stephen Gilbert, Ph.D., Iowa State University
Michael Dorneich, Ph.D., Iowa State University
Brian Gilmore, Ph.D., John Deere
Bruce Newendorp, John Deere

The practice of human factors in agriculture presents numerous challenges for the researcher. Difficulties include measuring operator behaviors in the agricultural field as well as identifying individual tasks, order of tasks, length of tasks, and operator motivation for each task. To confidently build a baseline for how operators use and appropriate their resources during the planting agricultural season, a variety of qualitative and quantitative research methods were combined to create OCTA (operator-centered task analysis), a hybrid methodology to observe, document, explain, and potentially predict operator behaviors in the field. The OCTA model draws from four main methodologies: observation, interview, behavioral and interview coding, and task analysis. This work describes the development and implementation of OCTA, and how to replicate its use. While the OCTA methodology was developed in an agricultural context, it can be generalized for use with nearly any observable human-machine interaction system.

Introduction

The world population is projected to reach 9.1 billion people by 2050, which will require a 70% increase in food production from where it is today (FAO, 2009). This will require improving agricultural efficiency at all levels of the process, including at the micro-level of human-machine interactions. Such improvement first requires a better understanding of agriculture-related human factors. Little work has been conducted in documenting detailed steps of agricultural processes from the operator's perspective. This work addresses this gap by proposing an operator-centered task analysis methodology, or "OCTA." OCTA is a hybrid of existing human factors methodologies, and can be implemented to understand human-machine interactions in a range of domains and contexts. The first step of OCTA is learning how the operator interacts with their systems via field observation. The researcher builds on that grounded truth.

With many systems that are relatively commonplace, there is a disconnect between the general perception of a process and the reality of how an operator completes such work in the field. This stems from two issues, the first being that the builders of interactive systems often cannot or do not fully understand how their product is used. Secondly, data is often collected via self-report as this is a simple and low-cost avenue for companies to gain feedback about their product. However, self-reported data may lack accuracy; for example, it can be affected by recall bias and affective phrasing (Lazar, Feng, & Hochheiser, 2010). Indeed, there are opportunities within many domains, including agriculture, in which the operator process has not been well-documented and therefore no baseline exists against which to compare future developments or competitor products.

The OCTA methodology for this completed work was developed within the agricultural cycle. The first step to deconstruct this very complex process is to select a single area within, and in this case the focus is on the soybean planting process in the Midwestern United States. With a focus on the planting process, existing known methods of observation and documentation are used together to assemble a new foundation for defining the operator's process. The planting process begins around harvest completion around November and proceeds through months of planning and preparation. It results in seeds properly buried in the field, usually in May. The entire process requires sizeable effort, time, and resources, as well as the ability to adjust at a moment's notice.

The OCTA methodology is comprised of elements from both qualitative and quantitative research. This process is outlined by beginning with a brief pre-observation interview to gain an understanding of who the operator is and what equipment and techniques he currently uses in the planting process. As compared to operator populations on which task analysis is typically conducted, agricultural operators are a unique group with certain challenges. That is, operators engaged in agricultural tasks are often attending to three different aspects of the tasks at hand. The first is the immediate work in front of them, the second is coordinating the logistics of the upcoming events, and the third is the alignment of high-level organizational goals. Agricultural operators in particular are under severe time constraints multiple times per year, all for different reasons. The typical agricultural operator must plant his crops within a relatively small window of time, to occur at the earliest planting time permitted by weather but after crop insurance planting dates. During the fall, crops must be harvested after maturation, preferably with enough time to dry to desired moisture levels, but prior to temperature decreases which will damage crops past the point of value.

Following the pre-observation interview, a live observation session is conducted, with the researcher shadowing the operator through all parts of planting, including equipment maintenance, a ride along in the tractor during

planting, and any clean up procedures operators may perform. During the live observation, a semi-structured think-aloud protocol is followed which is recorded with a combination of annotated audio and passive video. Following the live field observation, a brief interview is conducted to answer any questions the researcher may have. The interview data is then coded to find common themes and outstanding issues between operators. The video data is parsed using behavioral coding methods to determine actual time on task for specific actions and to create a baseline of performance. Behavioral coding has been used in a variety of domains, such as deaf studies (Ducharme & Arcand, 2009) and animal observation (Noldus, 1991); operator field observation a natural adaptation.

By combining these techniques, meta-themes begin to emerge, providing insight as to how operators are using their equipment, resulting in both intended and unintended consequences. The quantitative output of behavioral coding can then be used to support or refute existing claims and strengthen findings from the qualitative work. The end result produces a high-level hierarchical task analysis with elements of both cognitive work analysis and cognitive task analysis (Klein et al., 2003; Rasmussen, Pejtersen, & Schmidt, 1990). This output includes time on task, reported pain points, and areas of opportunity.

It is the intention of this research team that the OCTA process can then be taken to other existing areas of human factors, human-machine interaction, and human-computer interaction to help create a foundational understanding of how different technologies are currently used, thus informing future development and evaluation processes.

Practice Innovation

The OCTA successfully integrates existing quantitative and qualitative methods to create a hybrid methodology to observe, document, and report on complicated agricultural processes. When detailing how and why actions are taken in field work, especially when the work involves domain-specific equipment such as agricultural technology, existing single methods fall short of capturing the complexity and detail of the entire process.

The overall OCTA can be seen as a series of steps to explain a large system, with each step including a series of sub-steps which are broken down into individual operator actions. The initial step involves asking relevant questions which best serve to build the foundation of the OCTA. This work began by outlining a high-level overview of the planting process. This high-level overview was then shown to two experienced operators to for feedback about what major steps and processes might be missing, both overall and within each step. Once this high-level overview was vetted by the experiences operators, the first observation session was scheduled.

Researchers conducted a pre-observation semi-structured interview to construct a foundation of the operator's individual identity (Berg & Lune, 2011). The semi-structured interview was recorded by the iPad application Notability, which allows for annotated audio recording. By the conclusion of the pre-observation interview, a comfortable rapport was established and the observation would begin.

During the observation, the operator wore a wireless (Bluetooth) microphone, which was connected to the iPad for annotated note taking. The initial process included taking photos of all relevant steps with descriptions while timing with a stopwatch. After the first two observations, video was taken with cell phone cameras (see Figure 1) to record relevant steps from which timing could be extracted. The final iteration included mounting two GoPro cameras inside the cab of the tractor to record operator interactions and observe equipment changes in the field. During the live observation, a truncated set of pre-designed questions were asked concerning the most crucial activities, such as multi-step processes and priority switching simultaneous tasks. Throughout the duration of the live observation, a think-aloud protocol was used to have operators identify why specific actions were taken and what types of cues and triggers were used to prompt that action (Jaaskelainen, 2010). By using a think-aloud protocol, specific pain points and risks could be identified and subjected to follow-up questioning. Specific to the planting process, at any point during the observation when an operator seemed cognitively loaded (e.g., hesitant to respond), the research agenda was always halted to allow the operator to give full attention to the current task.

Figure 1. Image taken from field observation.

Figure 1 illustrates an example of why operators are required to become proficient in attention-switching activities. The four separate devices with screens shown in the photo each require some level of visual attention. Operators engage with the devices in response to: visual cues such as flashing on the screen; audio cues such as beeps from a particular device; or positional cues such as turning around at the end of the row, which leads them to check a particular display. For example, an operator will check to confirm that there is enough seed to make it to the end of a row prior to starting the row.

The operator pictured is using four monitors. The furthest to the left is the primary tractor monitor, which can display a wide variety of tractor and planter diagnostic information and is often used to display GPS information. The second factory device, which is smaller here, is often used to monitor diagnostic information. The third and fourth displays, mounted on the rail, are used to monitor planting functions. They display information relevant to the fertilizer being

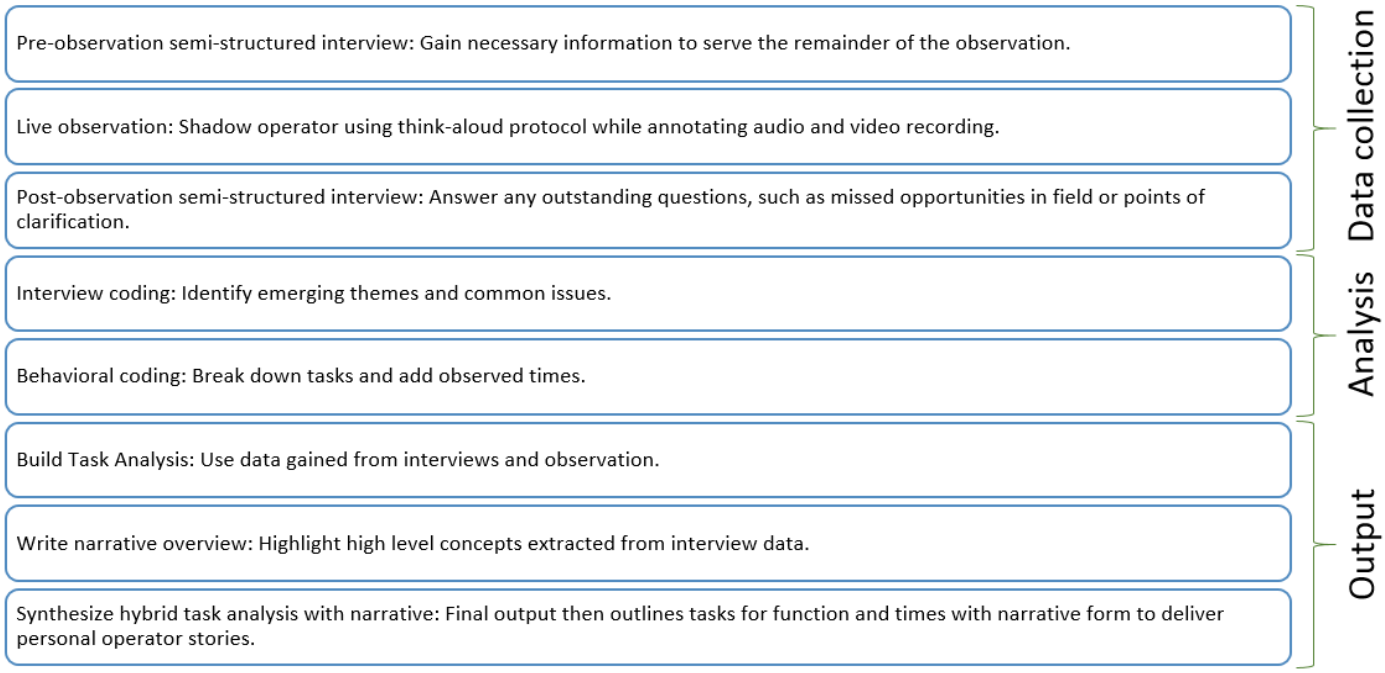

Figure 2. The complete OCTA process.

applied (left monitor) and information specific to the planter itself, such as seed rates, seed volume, and spacing.

Following the completion of the live observation, a brief unstructured interview was held to clarify any remaining questions or outstanding issues the researcher may have seen or not had time to ask about during the observation. After all questions had been answered to satisfaction, the data collection portion of this methodology was complete.

All interview data (including pre-observation, observation, and post-observation data) was then reviewed via annotated audio logs. Major recurring themes, or content categories, were identified and used to build the initial code book, for coding the remainder of the interview data (Lazar et al., 2010). The list of pain points and risks observed and described was enriched based on the interview data.

All video data from the observation was then reviewed and an initial code book was built based off of the first observation using an open coding approach (Corbin & Strauss, 1990). This grounded theory approach to building the video code book requires watching the initial videos multiple times but builds a strong, evidenced based foundation for all future observations. This work used The Observer XT as the tool to watch, annotate, and build the behavioral codebook (Zimmerman, Bolhuis, Willemsen, Meyer, & Noldus, 2009).

With interview and video data coded and organized, the task analysis was built. The framework was built on a hierarchical task analysis model (Wickens, Lee, Liu, & Gordon-Becker, 2003) with additional elements embedded. The principles of macrocognition were considered as the overall process of planting is one that requires decisions to be made under pressure and are complex due to an overload of data (Klein et al., 2003). Elements of cognitive work analysis (CWA) were also incorporated as the planting process, and agriculture at large are in a state of constant change with increasing amounts of technology and data available to operators every year (Rasmussen & Pejtersen, 1990).

A narrative overview was written to summarize the experience and findings of the research team overall. This narrative characterized the major emerging themes found from the interview data and highlighted unexpected results found after behavioral coding was completed. The risks outlined were also transformed into opportunities for improvement and rough monetary valuations were placed on each opportunity for savings.

The final narrative and task analyses were then compiled into a single report and delivered. The final complete process can be seen in Figure 2.

Findings

The data shared here are an excerpt of the complete findings. Three separate operators were observed over multiple sessions through a single planting season. The average operator age was 33 years old, with an average of 9 years of planting experience and farming an average of 1650 acres of primarily 80 or 160 acre fields.

After coding the interview data, results ranged from demographic information to unique emerging themes. The information discovered from these emerging themes was used to highlight unexpected findings, refute existing claims, and support existing claims. Examples of findings categories were age, experience, acres farmed, acres owned, equipment used, equipment likes and dislikes, equipment selection rationale, technology used, assistance used, features desired, and a variety of anecdotal examples to explain a wide variety of choices.

Results from the behavioral coding afford a more quantitative report to be generated. A complete overview of each step within the planting process was outlined, including

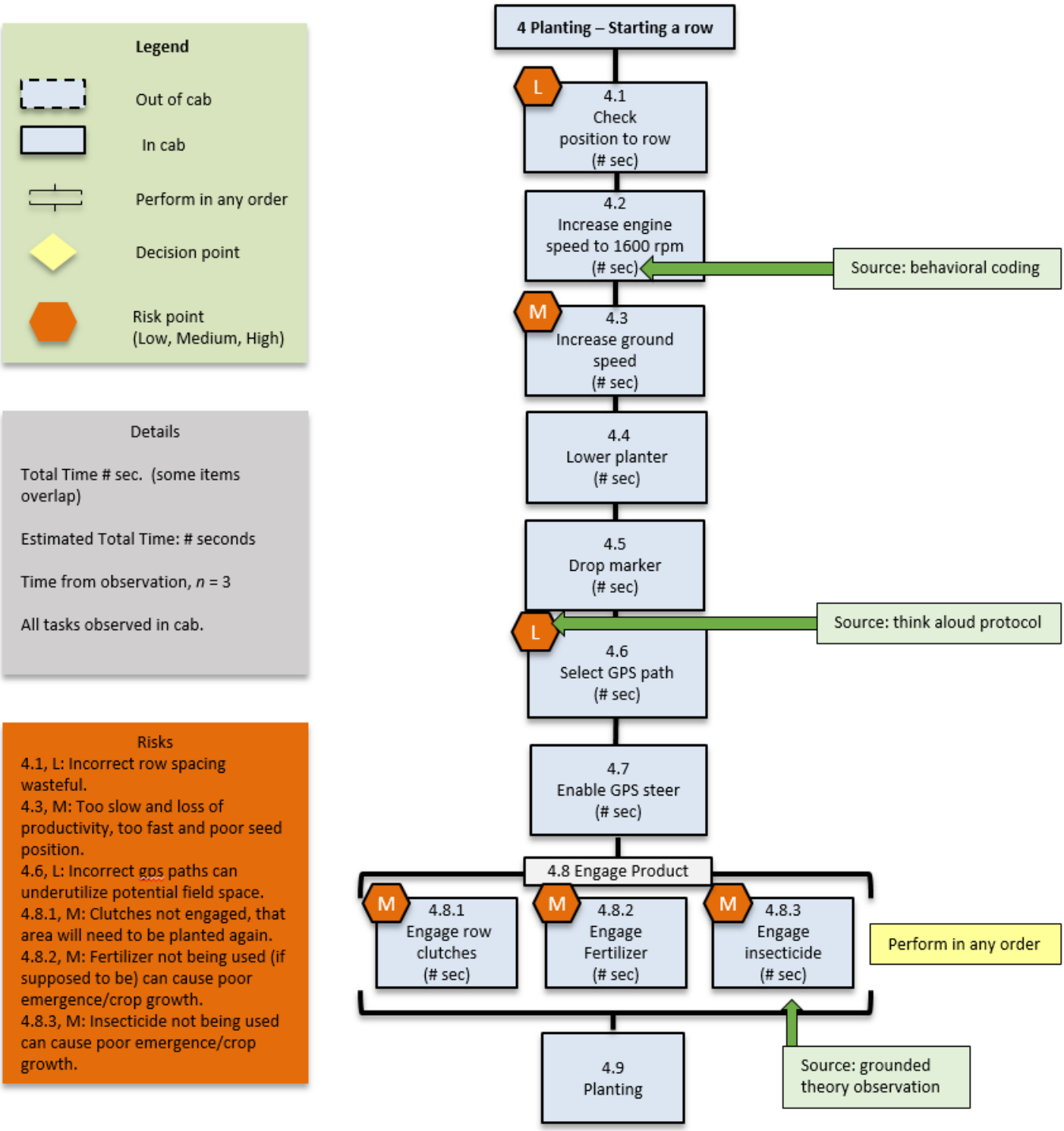

Figure 3. The observed results from one step of the planting process.

sub-steps to highlight the details within each high level step. The following outline shows the overall structure with an example task being shown. Each of the steps and sub-steps has a time associated with it, risk factors if necessary, and insight gained. See Figure 3 for an example of the OCTA output of step four, "Planting – starting a row." Step times were removed for confidentiality.

1. Planter preparation, physical
2. Planter preparation, monitor
3. Tractor-planter connection
4. Planting – starting a row
    a. Check position to row
    b. Increase RPM to 1600
    c. Increase ground speed

d. Lower planter
e. Drop marker
f. Select GPS path
g. Enable GPS steer
h. Engage product
    i. Engage row clutches
    ii. Engage fertilizer
    iii. Engage insecticide

5. Planting – planting in row
6. Planting – Ending a row
7. Mid-field refill
8. Tractor-planter disconnection
9. Planter storage

Lastly, all observed pain-points were then converted into opportunities to yield specific resource (time and money) gains from the perspective of the operator if improvements or changes were made to the existing system. An example from operator feedback is "Yield map evaluations and soil analysis are time-consuming." The opportunity identified from this is "There is an opportunity to ease a time burden on the operator." This opportunity then has a preliminary resource cost-savings associated to it, e.g., "Improved yield map evaluation and soil analysis software could reduce use time by up to 25%, saving 15 minutes per field analyzed. This saves an operator with 1000 acres 187 minutes of work."

The operator narrative and hybrid task analysis are the primary deliverables for the OCTA, with the pain-points to opportunity matrix as a third possibility if relevant.

Discussion

As human-machine interactions and human-computer interactions become more complex and cross additional domain boundaries, the importance of having a methodology that can capture who, what, when, where and why becomes increasingly important. The development and use of OCTA within agricultural systems has shown value by successfully documenting operator behaviors and underlying thoughts, triggers, and motivations. Fusing the quantitative and qualitative measures makes for a stronger argument toward the improvement of any system inspected. Additionally, the video and audio captured high quality, contextualized, anecdotal evidence to share with others when persuasion or story telling is the objective of the work. This process sets a groundwork for infusing techniques and can also be complemented by additive methodologies in the future. Adding biofeedback measures such as heart rate or skin conductance could help reflect operator mental workload (Meusel, 2014) or CAN message tracking could give insight into how individual buttons or features are utilized.

The OCTA hybrid methodology can be taken outside of agricultural processes and applied to many complicated operator interactions such as driving a vehicle, operating forestry equipment, or even performing surgery. As companies continue to optimize and refine their products and processes, benchmarking existing processes and comparing continued improvements will become paramount to maximizing efficiency, regardless of domain. The OCTA methodology successfully merges the quantitative findings with strong qualitative support and documents actual operator behavior to personalize the stories being told.

Other researchers are encouraged to use the OCTA methodology outlined here and adapt it as dictated by the needs of their specific work.

Acknowledgments

Thanks goes to JD Mayer and Nolan Dodson for data collection and analysis and to the operators who allowed observation during one of the busiest farming times of the year. This research was sponsored by Deere & Company.

References

Berg, B. L., & Lune, H. (2011). *Qualitative research methods for the social sciences (8th Edition)*. Essex, England: Pearson Education Limited.

Corbin, J. M., & Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative Sociology*, *13*, 3–21.

Ducharme, D. a, & Arcand, I. (2009). Using Noldus Observer XT for research on deaf signers learning to read: an innovative methodology. *Behavior Research Methods*, *41*(3), 833–40. doi:10.3758/BRM.41.3.833

FAO. (2009). How to Feed the World in 2050. *Population and Development Review*, *35*. 837-839. doi:10.1111/j.1728-4457.2009.00312.x

Jaaskelainen, R. (2010). Think-aloud protocol. In Gambier, van Doorslaer (Eds.), *Handbook of translation studies* (371-373). Amsterdam: John Benjamins Publishing.

Klein, G., Ross, K. G., Moon, B. M., Klein, D. E., Hoffman, R. R., & Hollnagel, E. (2003). Macrocognition. *IEEE Intelligent Systems*, *18*(3). 81-85.

Lazar, J., Feng, J. H., & Hochheiser, H. (2010). *Research Methods in Human-Computer Interaction*. West Sussex, UK: Wiley and Sons.

Meusel, C. (2014). *Exploring mental effort and nausea via electrodermal activity within scenario-based tasks* (Master's thesis). Iowa State University.

Noldus, L. P. J. J. (1991). The Observer: A software system for collection and analysis of observational data. *Behavior Research Methods, Instruments, & Computers*, *23*(3), 415–429. doi:10.3758/BF03203406

Rasmussen, J., Pejtersen, A. M., & Schmidt, K. (1990). *Taxonomy for Cognitive Work Analysis* (Risø-M-2871). Roskilde, Denmark: Risø National Laboratory.

Wickens, C. D., Lee, J. D., Liu, Y., & Gordon-Becker, S. E. (2003). *Human Factors Engineering* (2nd ed.). Upper Saddle River, New Jersey: Prentice Hall.

Zimmerman, P. H., Bolhuis, J. E., Willemsen, A., Meyer, E. S., & Noldus, L. P. J. J. (2009). The Observer XT: a tool for the integration and synchronization of multimodal signals. *Behavior Research Methods*, *41*(3), 731–5. doi:10.3758/BRM.41.3.731