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Sociological and Biological Insights on How to Prevent the Reduction in Cognitive Activity that Stems from Robots Assuming Workloads in Human–Robot Cooperation

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Abstract: The reduction of cognitive tasks brought about by new developments in service-robots' collaboration with humans in working environments has given rise to new challenges as to how to address safety issues. This paper presents insights from biology, cognitive/neural sciences and sociology that can conquer these new challenges. The main focus lies in sociological variables that ensure safe human–robot interaction in working environments rather than addressing biological ones (avoiding bodily harm) or purely cognitive ones (avoiding any signals that are outside the human's sensory comfort zones). We will present an approach on how to integrate behavioral patterns into the robotic system in order to prevent the problem of reduced cognition in relation to essential features, which are necessary for carrying out this pattern in the context of a human–robot interaction with non-humanoid robots (which is the most typical design of robots used in work environments).

Keywords: human–robot cooperation; breaching experiments; work safety; sociology; biology; interdisciplinary perspectives

1. Introduction

In our paper we will focus on human–robot cooperation in work environments from the perspective of human–robot interaction, and the insights that we have gathered so far based in experiments conducted in the Fabrication Laboratory "MTI-engAge" at the Technical University of Berlin. Within the study of human–robot interaction (HRI), the specific field of cooperation between humans (workers) and service—or even social—robots in industrial and production settings is an up-and-coming but crucial topic. In this field, aspects of work safety are substantial and are mainly emphasized as an issue of avoiding somatic harm. However, the more advanced the robots become, the more cognitive issues should be taken into consideration. So far, most of the robots used in work environments are industrial robots that are used in production processes. Safety is ensured by separating them from the workers through security spaces. The growing need for robots to take part in collaborative actions with human workers clearly raises completely new challenges and demands new approaches for addressing safety issues. In our paper, we emphasize the fact that even if the interaction with the robot is intuitive and therefore unproblematic, it will pose a danger to safety due to an increased reduction of cognitive tasks as the robots assume this workload for the involved humans. If the robot fulfills the collaboration task with the human in a routinized way (unlike the human), the human will adapt to the robot's predictable behavior very quickly and in doing so reduce his or her attention to a quite dangerous level. To address these new challenges and develop strategies to avoid them, we argue that the construction of interactive working robots can benefit from a multi-perspective view drawing from various disciplines in order to achieve the goal of identifying problems that have not been common till now.

This paper presents insights from biology, cognitive/neural sciences and sociology regarding perceptual, constructional and especially interactional issues. Biological and neurological concepts help understand how humans perceive and process their (cooperative working) environment and allow these insights to be transferred to the construction of robots with the purpose of facilitating a secure human–robot interaction. Sociological insights may help in the evaluation of human–robot interactions in contrast to human–human interactions (HHI) and contribute important social factors. Our main focus is on sociological aspects to ensure a safe HRI within working environments, rather than addressing biological ones (avoiding bodily harm) or purely cognitive ones (avoiding any signals that are outside the human's sensory comfort zones). On the one hand, these issues are of course indispensable; on the other hand, we believe that it is important to go one step beyond these obvious factors. To achieve these goals, we propose the use of a conceptual instrument in the form of what we call a "behavioral crisis pattern", which should be adapted to the specific robotic system and work environment according to perceptual-based principles from biology and basic sociological assumptions regarding the main factors that characterize interaction among humans. A critical component for HRI in work environments is avoiding strong routinization and a strong reduction in the human's attention. Especially if the robot is assuming a large workload for the human, the stated problem could arise and pose serious danger to safety. We would like to clarify from the beginning that the term "crisis" is a conceptual term taken from a very circumscribed approach to HHI within sociological theories mainly known as "ethnomethodology." Of course the humans cooperating with robots are not involved in a behavioral crisis in an everyday sense; we use the term "crisis" in a traditional ethnomethodological meaning to describe a robot behavior that surprises the human user. To achieve this goal and the intended benefit, the robot simply has to act in such a way that is slightly different from the human's expectations. When expectations do not meet with such surprise after a fair amount of interaction experience, humans automatically tend toward routinization.

To address this problem via an interdisciplinary perspective, we want to present some biological foundations concerning perception, feedback, attention and stress in Section 2. Subsequently, we will discuss the sociological contribution to HRI research in terms of some basic assumptions about sociality and social interactions, a theory-driven evaluation method and our own initial groundwork with an experimental setup. The combination of these insights and theoretical assumptions represents an important initial step toward a sociologically elaborated approach for the development of cooperative robots in a work environment. In Section 4, we will discuss and present our ideas on how to integrate a behavioral pattern in the robotic system to prevent the problem of reduced cognitive activity through robot assumption of workload in relation to essential features that are needed to carry out these patterns when realizing an HRI with not-humanoid robots (which is the most typical design for robots used in work environments). In the final section, we conclude with some prospective remarks concerning the measurement of our suggested instruments in the form of a behavioral crisis pattern.

2. Biological Foundations: Perception, Attention and Feedback

In this section we will discuss the basic human senses and cognition capabilities that are involved in the design of effective patterns for a successful HRI. In addition to sociological assumptions that are, for obvious reasons, much more culture-related and therefore biased by historical and contextual factors, the biological outfit should be taken into account as a pillar and cornerstone for the overall design of the interaction between humans and robots. We argue that the consideration of these very basic biological insights—somatic as well as cognitive—are usually missing in HRI research focused on interaction patterns and their importance for the design. Especially in terms of safety, it is of paramount importance to combine both biological and sociological insights. However, from a sociological point of view, once biological and cognitive criteria are sufficiently considered and incorporated into the robot design, the character of the interaction will be the primary concern. We first discuss the way humans perceive their environments and to what extent the human's sensory comfort zone in the interaction with a robot should be taken into consideration when designing the robot. Then we present some crucial aspects of the cognitive process, as well as important measures to ensure that the experience of interacting with a robot is not a stressful one. These remarks represent the foundation for the sociological approach, and from our point of view, they should also be taken into account by engineers, psychologists and designers dealing with HRI in general.

The senses are windows into the human's world. To discern and interact with our environment, we humans need perception and feedback. The senses receive information from the environment at a rate of 109 bit/s. Only 101–102 bit/s of this information are added and processed consciously. The outstanding information will be processed subconsciously or filtered out and not used. Humans produce about 107 bit/s by speech or motor information [1].

With regard to human–robot interaction we will focus on the senses of vision, touch, and acoustics. The body is affected, influenced, and/or impaired by the stimuli of the environment in various forms, generally via mechanical and electromagnetic waves. There are specific receptors in the sensory organs and each sensory cell has its adequate stimulus, which effects a specific sensory impression [1–7]. About 80% of the information from the surroundings contributes to the optical sense and thus constitutes the majority of our perception [2]. The stimulus enters through the special cells of the retina in the eye and to the optic nerve the brain. Signals are forwarded over the thalamus to the visual pathway from the occipital lobe to the temporal cortex or parietal lobe, where they are processed. The pathway from the eye to the brain requires about 250–350 ms [1–8]. Humans' spectrum of vision comprises a range of 380–780 nm. Anything exceeding this color range may result in cognitive impairment or even in an eye injury [2,7]. In order to make the worker feel comfortable, a proper and pleasant color choice is important for an easier interaction.

Haptic perception takes place via the largest human organ, the skin. Mechanical stimuli are received by various receptors, which are located in the skin at different depths and sense various types of haptic stimuli [1–8]. Information is passed via the spinal cord and the thalamus to the cerebrum, which has a specific structure. This area is a "somatosensory" area and represents the density of receptors of the various body regions and the processing of the arrival stimuli on these regions [2,4,6,7]. Reaction time is about 80–150 ms [2]. Handles, switches and pads should be designed to appeal to the relevant hand areas with the appropriate receptors so that the humans can receive the required feedback from the robot.

Sound waves are cupped by our ears and passed through the ear canals into the complex construction of the inner ear. The movement of the membranes in the inner ear causes membrane voltage changes and the innervation of the auditory nerve. This information is transferred over the thalamus to the auditory cortex. Reaction time is about 100–150 ms. A human can hear sounds between 20 and 20,000 Hz [1–8]. There is a decrease in the ability to concentrate and a feeling of uncertainty or unease for frequencies lower or higher. A suitable frequency and intensity of a sound should be chosen in order to make the human feel comfortable and perceive the tones clearly. To enable a simple, safe and intuitive interaction with robots, it is important to consider humans' sensory comfort zones. This leads to the best registration of stimuli and optimal use of humans' cognitive capabilities.

In order to counteract overstimulation, the selection of the amount of information begins in the sensory organs. Other filtering processes occur in additional regions of the brain [3,4,6,7]. Perception is indirect, meaning the stimulus information is passed to the appropriate areas of the brain via the thalamus, which serves as a hub, thus filtering the amount of information and distributing it. Information from the sensory organs is decoded and interpreted by the specific regions of the brain, which communicate with one another. An overall picture of the environment is created by the composition and conscious reconstruction of information. Remarkably, the brain can rearrange individual fractured perceptions and fill in gaps in perception. The brain has to influence our perception of time during its performance to create continuous, seamless perception. Perception is also a process of memorization, of storing patterns of perception, and it depends on our attention [2].

While interacting with a robot, both the human and the robot should receive feedback from the respective interaction partners in regard to their own actions. Feedback can be given via one or more sensory modalities and should ensure increased attention and may provide more information. This is mentally stimulating and increases humans' attention. In order to interpret the robot's feedback and the behavior properly, humans should receive sufficient feedback about the robot's behavior. Humans modify and adapt their behavior based on whether or not their expectations are fulfilled. The robot can interact with different systems and provide feedback. The robot's "perceptions" could be limited to the three senses described above. The robot can perceive the environment through sensors and various camera systems. The sensor signal absorbs and transfers them to the robot's controller. With advanced developments in technology, it is in theory possible for the robot's sensors to detect a wider range of stimuli than humans' physiological senses. On the one hand, this could raise questions of how the robot should employ these capabilities, because the human may eventually lose authority over the robot; on the other hand, the robot could use its wider range of stimuli to compensate for its impaired capabilities for social interaction. Sensors are available with a variety of measurements for a variety of types of changes in the environment [9,10]. However, the technology has restrictions, for example on lifting items that are compliant.

The robot can communicate, for instance, via light. It should transmit different information with different colors, to differentiate between status feedback and action feedback. Looking at this in more detail, there are three levels of feedback. Action feedback gives the user immediate feedback about the fact that the technical system recognizes his or her action or encourages the human partner to perform a specific action. Status feedback gives the user feedback on the degree of achievement of objectives, especially when the reaction of the robot is not obvious or of longer duration. Objective feedback gives the user indication as to whether the objective of an action has been achieved and thus completes the current operation step [11]. The robot should always make clear its intentions using unambiguous actions and/or feedback. Robots relieve people in their work. However, the reduction of a human's workload (operator action) by a robot should not exceed the point where humans lose motivation and/or get bored. Furthermore, the proper handling/execution of the task will suffer in its precision when it is carried out by a robot.

The slow decrease of attention levels can lead to errors. Errors can build up or lead to fatal errors after tasks become routine. As this can lead to stress, the demanded mental/cognitive performance will be further reduced. So it is important that the person is integrated into automation processes or cooperation with robots. In this situation, the human will always be required to exercise mental attention and increased awareness to carry out its operational model and maintain the upper hand. In addition, regular training of key action sequences could reduce the potential of hazards. The task of the person should always be so cognitively demanding that he or she accepts the usefulness of his or her actions [11]. Attention designates people's ability to choose from the variety of sensations and information that hold general interest in order to find those that are important for planning and executing actions (selection function of attention). An important prerequisite for this selection process is sufficient alertness (activation function of attention) so that the relevant information can be included and reliably processed.

Generally, people fail to retain a high level of attention over long stretches of time. There are 5 elements of attention:

- Attention activation (alertness) is the ability to produce responsiveness.
- Sustained attention is the ability to observe relevant stimuli over a longer period and react to these stimuli.
- Selective attention is the ability to select certain features of an object or situation, respond to these stimuli quickly and reliably and not to be distracted by irrelevant or unimportant stimuli.
- Divided attention is the ability to perform two or more tasks simultaneously.

- Executive attention is described as the ability to deliberate control and control the processing of information.

All attention tasks activate similar regions in the brain, including the anterior cingulate gyrus and the right medial frontal lobe [12]. Stress influences both the motor and the cognitive performance range and therefore the aspects of perception and attention. It is a psychophysical alarm reaction which is expressed as increased activity of the autonomic nervous system and the endocrine organs. This leads to an increased release of biogenic amines, such as norepinephrine, dopamine and epinephrine as well as increased blood pressure and other physiological changes. Stress can be caused by various stimuli from the environment or the organism itself. Likewise, an interaction with a robot can also cause stress. Every interaction includes the human's feedback and responses to the robot. In order for the robot to respond properly and adaptively to the human, the human can give feedback on the visual channel through his or her posture, expression and gestures. Auditory communication is also possible by using command information.

3. Sociological Contribution to HRI Research

From a sociological point of view, it is fruitful to consider HHI as a foil for the design of a safe HRI in work environments. To understand the key factors that define HRI as sound and superior to developments that focus on mere functionality, it is helpful to compare HRI to HHI as a reference point. Even if the implementation of HRI deviates from the standards of HHI, we claim that the orientation towards HHI is the key for the design of a proper and human-centered configuration of HRI. What are the basic preconditions for an interaction between a human and a robot that could be characterized as "social"? In the first instance, it is important to notice that even human interactions involve a great range of degrees of sociality. Human technical behavior can also range from determined routine and rule-governed actions to contingent forms and complex behaviors, which can best be described with an intentional vocabulary, as they call for inferences from observable conduct to unobservable inner states [13].

Human interactions are structured by expectations and the interaction partners formulate expectations based on what the other expects (expected-expectations). Although expectations are not disappointed very often in everyday contexts, deviation is a phenomenon humans are familiar with in social interactions. It refers to the fact that among humans, there is always the possibility to act differently. Theoretically, this constellation is referred to as double contingency [14]. Niklas Luhmann also highlights the fact that uncertain expectations are more stable than certain ones, as they imply their opposite and the possibility of disappointment is expected at the same time [15].

Keeping that in mind, another important aspect concerning sociality in interactions is that humans tend to behave socially not only towards other humans, but also towards robots, technological objects, media and nature [16,17]. This tendency to anthropomorphize arises from the circumstance that the major part of the competence to interpret the world has its roots in social interactions: social knowledge is transferred to other areas. Yet, social responses may be induced by special properties of an object or a technology [16]. To identify these properties is the task of empirical research. The tendency to anthropomorphize robots is particularly high, as they are embodied and socially embedded [18]. Anthropomorphization is closely related to the attribution of intentionality, which in turn points to a kind of agency that is ascribed to the robot [19].

Several studies in the field of HRI have led to the assumption that the robot's gaze is crucial for the assessment of the interaction and has a significant impact on a positive process in performing a cooperative task [20–22]. Even if a "point of interaction"—embodied as a face with eyes—would seem completely irrelevant for the function of a robot within work environments, it can be vital for a healthy, cognitive, exonerative and altogether safe HRI design. In the following paragraphs, we want to present our initial findings, namely a theory-driven evaluation framework for HRIs and an experimental setup to tackle the question as to the relevance of a higher degree of sociality in HRI interactions.

Elsewhere, we proposed a sociologically inspired method to evaluate HRIs based on "breaching experiments" (Garfinkel), combined with a thorough "frame analysis" (Goffman) to account for specific contextual conditions [23]. We argued that this method is particularly suitable for research in laboratory and development environments, as experiments based on breaches in the field constitute a strict test for a robotic system. Harold Garfinkel used breaching experiments to demonstrate the fragility of social order and the latent mechanisms humans use to coordinate themselves with their environment [24]. A crisis questions the unquestionable and the boundaries of an assumed reality. The basic idea of the breach in this regard is that it can reveal something about "normality". If humans adopt social repair strategies to keep the interaction going when confronted with an interaction flaw on the robot's part, they transfer these basic social mechanisms from HHI to HRI situations and thereby give the interaction a social note. In combination with breaching experiments, frame analysis, upon which Erving Goffman elaborated in his microstudies on social interaction, is of paramount importance because it assesses the crisis adequately by taking into account the specificities of the context [25].

The second basic premise that we are currently working on in our interdisciplinary research group is an experimental setup to examine the quality of an HRI with a non-humanoid robot in two experimental conditions. The robot is biomimetically constructed out of pneumatic muscles according to the biological model of an elephant trunk and is thereby inherently compliant. We investigate the relevance of a point of interaction with and without a LED light for the quality of the interaction in a framed breaching experiment approach. The interaction sequence between the experimentee and the robot is videotaped and analyzed qualitatively using video interaction analysis [26]. Furthermore, the participants are interviewed after the interaction and are asked to fill in a quantitative questionnaire that investigates different aspects of the interaction with the robot.

The basic ideas of our methodological framework and experimental setup can easily be transferred to HRIs in work environments. Although the majority of robotic research is still settled in laboratory contexts (for field studies see e.g., [27–29]), an expansion that would include work contexts would be desirable to gain results about HRIs in everyday situations. We argue that the implementation of basic social features, even in non-humanoid robots in work environments, can result in a superior interaction experience, which is increasingly important as both the interface and the cooperation between worker and machines—i.e., robots—are becoming significantly more interactive. Even if the crises induced within the so-called "breaching experiments" are real crises due to the severe irritations they can evoke, the goal even here is still to observe and identify how humans are experts trained in repairing the breach. In this regard the approach assumes that humans always have to adjust their behavior slightly when interacting with each other. Humans usually don't realize this necessity and don't even identify it as a distinct task—it just happens all the time. This is also a significant difference between interacting with a machine and a human: A machine becomes predictable after a certain amount of time; a human will never be. This is true not only because humans have the potential to surprise one another, but also because every interaction is a new one that depends on a similar definition of the world, which has to be established anew with each interaction. Therefore, we're not proposing building robots that feature a crisis behavior, but rather implementing a feature very common in HHI consisting of small perturbations that in no way infringe on perceptions of reliability and trustworthiness.

In the following section, we would like to transfer our proposed method of framed breaching experiments conceptually to field studies in the work environment and thereby introduce a "social" crisis as an instrument to foster attention in human–robot collaborations.

4. Implementation of a Behavioral Crisis Pattern to Prevent Reduced Attention due to Assumption of Workload

What can we derive from the biological foundations for perception, attention, feedback and stress and sociological insights into basic conditions of social interactions and their translation to HRI situations for human–robot collaborations in work environments? Our leading problem was derived from findings on feedback systems designed to lessen the human user's workload, which point out that with a high degree of reduction in this workload for the human, the risk of reduced attention increases. We argued that once basic work safety is ensured, and by this we are referring to avoiding physical injury, secondary problems arise in human–robot collaborations, which can affect work safety indirectly in the fashion of decreased attention on the human's part, due to strong routinization.

Based on the principle of deviation and expectation flaws, which is used in breaching experiments, we suggest implementing an instrument in the form of a behavioral pattern. This behavioral pattern would trigger a crisis directed solely towards human expectations and can hence be assumed to be social in nature. The robot's feedback shall thereby remain within the comfort zone of human perception (in biological terms), but demand the user's attention intermittently with reference to his or her expectations (in sociological terms). The most basic prerequisite for the functioning of such a (social) crisis is the anthropomorphization of the robot—as the tendency to ascribe human aspects to the robot's behavior—which is in turn the first stage for the shaping the human interaction partner's expectations. Drawing on theory and research, robots provoke these basic intentional ascriptions per se, which easily result in the human interaction partner assuming a certain agency [16,19].

The crisis functions through expectation flaws that can offer a starting point for further anthropomorphization, if they initiate an interpretation process of the observable behavior, drawing on intentionally described inner states. Yet if the crisis were too fundamental, the interpretation of a malfunction would be the more obvious, which would lead to frustration on the human user's part rather than increased attention. What we have in mind could be described as (re-)establishing awareness, not alertness. Two examples may be helpful to further clarify the nature of the crisis pattern we have in mind and the notion of awareness vs. alertness. We will first present a possible scenario in HHI on the intended level of slight surprise due to an unexpected behavior from an interaction partner. Assume that, after 10 years of marriage, a wife or husband asks his/her partner if he/she really wants coffee without sugar. On the same level in the field of Human–Machine Interaction, a good example could be described with a dialog between a driver and his/her self-driving car. After a couple of months on the way to work, the car asks the driver if he/she would like to turn left instead of turning right as they usually do. There will be a short moment of surprise leading to a slight degree of awareness, just enough to "wake up" the driver, letting him/her be sharp and cautious with regard to the traffic and his or her driving (even if the car is driving, he/she is still in charge and should always be able to take over if the autopilot fails for some reason).

In order to be able to consider this important aspect of crisis in a working environment of cooperation between humans and robots, it is crucial to differentiate the complexity of the interaction setting. On a very basic level, as described by Kahn et al. [30] with the term interaction pattern, the breach we have in mind could be induced by the robot not by deviating from the expected behavior per se, but rather by slightly varying the action in question. For example, a typical interaction pattern in work environments could be the passing of objects between the robot and the human (and vice versa), in this case the breach could be accomplished by the robot by slightly altering its position and/or movement as well as velocity, etc., from time to time in an unexpected way.

In a more complex setting when the cooperation is based on expectations towards a certain role (which could be described as a stable set of expectations toward a person holding a well-established position in a specific context), the crisis could and should be more profound. To overcome the danger of reduced alertness due to a routinized assumption of cognitive tasks by the robot, the robot could invoke a crisis by passing the wrong object or questioning the appropriateness of the demanded object. Of course performing a breach of this kind, which is much more substantial, is a delicate matter that has to be implemented very carefully, without endangering safety. From a sociological point of view it is of paramount importance to distinguish the different framings involved in working environments characterized by human–robot cooperation. Depending on the level of complexity (from basic interaction patterns to complex settings characterized by role allocation), the breach should be realized by adopting quite diverse strategies to obtain the same effect. However, a sociologically informed way of implementing such a breach can be easily designed simply by relying on the sociological theories dedicated to these different levels of complexity (e.g., basic patterns have been analyzed very well and described in ethnomethodology [24] and symbolic interactionism [31], and standardized interaction in predefined role allocations within stable contexts in role theory [32,33] and structural functionalism [34]).

Regardless of the complexity of the situation, the breach should be able to interrupt the flow of meshed expectations and, in doing so, the routinized sequence of actions, forcing the involved entities to focus on the meaning of the actual interaction by activating their attention on the history of a prior chain of actions and reactions toward the common goal of the cooperation [35]. At the same time, the breach induced by the robot should never lead the human to question the meaning of the cooperation itself or whether or not the robot is functioning properly. Therefore, the estimation (on the part of the human interaction partner) of the assumed level and the framing of the interaction are very important factors in designing the right type of breach. The framework established by Burghardt and Häußling [36] regarding a sociological model of human–robot interaction provides a helpful tool for identifying the character of the interaction and designing an adequate breach.

Without knowledge of ethnomethodology as a sociological approach to understanding how individuals re-establish and maintain order as well as stable interaction patterns in everyday life situations, our notion of how to solve the problems of reduced awareness in typical, contemporary human–robot cooperation tasks could be easily misunderstood. It could even be perceived as a dangerous way of preventing reduced awareness, or a way of jeopardizing safety and the trust the human subject has towards technology. The latter would lead to a catastrophic situation, because after a short while, workers would not be willing to work with robots they felt were highly unpredictable and not trustworthy. Therefore, it is important to keep in mind a few basic assumptions about how interactions between humans are understood in the previously mentioned ethnomethodology. Ethnomethodology assumes that in every HHI, the meaning of the issue at stake as well as all the relevant aspects needed to deal with it have to be reestablished by the entities participating in the interaction itself. There will be always slight adjustments, little signs or words to clarify what is meant. The meaning of a word, an object, etc., is never 100% clear and is always established ex post as an effect of the interacting partner's reaction. Therefore, HHI demands and automatically leads to a certain degree of awareness on the part of the interacting persons. Our approach is in this regard a very gentle way of increasing safety, since it involves a very common feature of HHI and proposes to transfer it to the design of HRI.

5. Conclusions and Measuring Remarks

Our methodological framework is based upon biological and sociological foundations in the form of a behavioral pattern instrument, and by transferring this framework to robots in work environments, we can investigate to what extent the implementation of basic social patterns—e.g., a point of interaction—is beneficial for the cognitive load, the stress level and the overall quality of the interaction, even if the robot does not always perform as expected. The approach is suitable for a field experiment, as the experimental condition is solely in the robotic system (and can be compared to those situations without social crisis) and no other external factors have to be controlled. With such an experiment, one could figure out if a social crisis is beneficial and if so, how it should be designed (e.g., frequency, duration and severity of non-expectancy). What we are aiming for could best be described as achieving a higher degree of awareness rather than some sort of alertness. It is crucial to bear in mind the parallels between the description of HHI provided by ethnomethodology and our approach in order to design safer HRIs in work environments by using small perturbations rather than actual crises (in a strict sense), and without destabilizing the perceptions of reliability and trustworthiness of the robot(s).

To conclude, we would like to suggest how data should be collected in such a field experiment. Considering the biological foundations of attention and stress, the crisis should raise the first and avoid the second. To find out if a situation is stressful, one can perform measurements of blood pressure and changes in alpha- and beta-waves using electroencephalography (EEG). Since beta-waves are difficult to interpret, alpha-waves are evaluated in terms of relaxation. Attention can be measured using various methods. One possibility is based on observational data with an inventory from Ehrhardt et al. [37] or the Munich attention inventory, designed by Helmke and Renkl [38]. Another possibility for gathering data on attention could be to create questionnaires. In addition, the subject's direction of sight and the time spent looking at a particular object can be detected by an eye tracking system.

From a sociological point of view, the interaction can best be analyzed qualitatively using video interaction analysis [26]. Additionally, measurement instruments, e.g., of satisfaction or wellbeing, can be used before and after the human–robot collaboration and interviews can be conducted about the interaction experience. We argue for an interdisciplinary approach when it comes to shaping the robot's design for contemporary human–robot cooperation that are able to reflect the enormously complex nature of interaction settings between humans and machines in today's work environments. Sciences focused on nature, living beings and their organization of common actions, and complex systems of functional differentiation should be consulted and intensely involved in the development of interactive and social robots. The successful and safe integration of cooperative robotic systems in work environments depends greatly on a genuine biological and sociological examination of the situation, which is becoming a biological and social issue. Rather than emphasizing purely technological, functional or user interface design perspectives, it will be increasingly vital to consider the aforementioned issues and similar topics from disciplines that—in addition to accomplishing evaluation tasks—have thus far played a relatively minor role in teams dedicated to the development of robots.

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References

1. Silbernagl, S.; Despopoulos, A. *Taschenatlas Physiologie*, 7th ed.; Thieme: Stuttgart, Germany, 2007. (In Germany)
2. Frings, S.; Müller, F. *Biologie der Sinne: Vom Molekül zur Wahrnehmung*; Springer: Berlin/Heidelberg, Germany, 2014. (In Germany)
3. Richard, D.; Chevalet, P.; Soubaya, T. *Biologie in Farbtafeln*; Springer: Berlin/Heidelberg, Germany, 2013. (In Germany)
4. Schmidt, R.F.; Schaible, H.-G. (Eds.) *Neuro- und Sinnesphysiologie*, 5th ed.; Springer: Berlin/Heidelberg, Germany, 2006. (In Germany)
5. Schmidt, R.F.; Thews, G. (Eds.) *Einführung in die Physiologie des Menschen*, 17th ed.; Springer: Berlin/Heidelberg, Germany, 1976. (In Germany)
6. Schmidt, R.F.; Thews, G.; Lang, F. (Eds.) *Physiologie des Menschen*, 28th ed.; Springer: Berlin/Heidelberg, Germany, 2000. (In Germany)
7. Thompson, R.F. *Das Gehirn: von der Nervenzelle zur Verhaltenssteuerung*, 3rd ed.; Spektrum: Heidelberg, Germany, 2011. (In Germany)
8. Carter, R. *The Human Brain Book*, 1st ed.; DK Publishing: London, UK, 2009.
9. Brooks, R.; Simon, A. *Menschmaschinen: Wie uns die Zukunftstechnologien neu Erschaffen*; Campus: Frankfurt, Germany, 2002. (In Germany)
10. Knoll, A.; Christaller, T. *Fischer Kompakt: Robotik*; Fischer: Frankfurt am Main, Germany, 2003. (In Germany)
11. Zühlke, D. *Nutzergerechte Entwicklung von Mensch-Maschine-Systemen: Useware-Engineering für Technische Systeme*, 2nd ed.; Springer: Berlin/Heidelberg, Germany, 2012. (In Germany)

12. Frommelt, P.; Lösslein, H. (Eds.) *Neurorehabilitation: Ein Praxisbuch für Interdisziplinäre Teams*; Springer: Berlin/Heidelberg, Germany, 2010. (In Germany)
13. Rammert, W. Where the action is: Distributed agency between humans, machines, and programs. Available online: http://www.ssoar.info/ssoar/handle/document/1233 (accessed on 21 September 2016).
14. Luhmann, N. *Social Systems*; Stanford University Press: Stanford, CA, USA, 1995.
15. Luhmann, N. *Trust and Power: Two Works*; Wiley: New York, NY, USA, 1979.
16. Dautenhahn, K. Methodology and themes of human-robot interaction: A growing research field. *Int. J. Adv. Robot. Syst.* **2007**, *4*, 103–108. [CrossRef]
17. Reeves, B.; Nass, C. *The Media Equation: How People Treat Computers, Television, and New Media Like Real People and Places*, 1st ed.; CSLI Publications: Stanford, CA, USA, 1998.
18. Dautenhahn, K.; Ogden, B.; Quick, T. From embodied to socially embedded agents—Implications for interaction-aware robots. *Cogn. Syst. Res.* **2002**, *3*, 397–428. [CrossRef]
19. Young, J.E.; Sung, J.; Voida, A.; Sharlin, E.; Igarashi, T.; Christensen, H.I.; Grinter, R.E. Evaluating human-robot interaction. *Int. J. Soc. Robot.* **2011**, *3*, 53–67. [CrossRef]
20. Moon, Aj.; Troniak, D.M.; Gleeson, B.; Pan, M.K.; Zheng, M.; Blumer, B.A.; MacLean, K.; Croft, E.A. Meet Me Where I'm Gazing: How Shared Attention Gaze Affects Human-Robot Handover Timing. In Proceedings of the 2014 ACM/IEEE International Conference on Human-Robot Interaction, Bielefeld, Germany, 3–6 March 2014; pp. 334–341.
21. Zheng, M.; Moon, Aj.; Gleeson, B.; Troniak, D.M.; Pan, M.K.; Blumer, B.A.; Meng, M.Q.; Croft, E.A. Human Behavioural Responses to Robot Head Gaze during Robot-to-Human Handovers. In Proceedings of the 2014 IEEE International Conference on Robotics and Biomimetics, Bali, Indonesia, 5–10 December 2014.
22. Zheng, M.; Moon, Aj.; Croft, E.A.; Meng, M.Q.-H. Impacts of robot head gaze on robot-to-human handovers. *Int. J. Soc. Robot.* **2015**, *7*, 783. [CrossRef]
23. Compagna, D.; Boblan, I. Case-Sensitive Methods for Evaluating HRI from a Sociological Point of View. In *Social Robotics*, Proceedings of 7th International Conference of Social Robotics (ICSR 2015), Paris, France, 26–30 October 2015; pp. 155–163.
24. Garfinkel, H. *Studies in Ethnomethodology*, 11th ed.; Polity Press: Cambridge, UK, 2007.
25. Goffman, E. *Frame Analysis: An Essay on the Organization of Experience*; Harvard University Press: Cambridge, MA, USA, 1974.
26. Knoblauch, H.; Tuma, R. Videography—An interpretative approach to video-recorded micro-social interaction. In *The Sage Handbook of Visual Research Methods*; Margolis, E., Pauwels, L., Eds.; Sage: New York, NY, USA, 2011; pp. 414–430.
27. Kanda, T.; Ishiguro, H. *Human-Robot Interaction in Social Robotics*; CRC Press: Boca Raton, FL, USA, 2013.
28. Sabanovic, S.; Michalowski, M.P.; Simmons, R. Robots in the wild: Observing human-robot social interaction outside the lab. In Proceedings of the 9th IEEE International Workshop on Advanced Motion Control, Istanbul, Turkey, 27–29 March 2006; pp. 596–601.
29. Scheeff, M.; Pinto, J.; Rahardja, K.; Snibbe, S.; Tow, R. Experiences with Sparky, a social robot. In *Socially Intelligent Agents—Creating Relationships with Computers and Robots*; Dautenhahn, K., Bond, A., Cañamero, L., Edmonds, B., Eds.; Kluwer Academic Publishers: Boston, MA, USA, 2002; pp. 173–180.
30. Kahn, P.H.; Freier, N.G.; Kanda, T.; Ishiguro, H.; Ruckert, J.H.; Severson, R.L. Design patterns for sociality in human-robot interaction. In Proceedings of the 3rd ACM/IEEE International Conference on Human Robot Interaction, Amsterdam, The Netherlands, 12–15 March 2008.
31. Blumer, H. *Symbolic Interactionism—Perspective and Method*, 10th ed.; University of California Press: Berkeley, CA, USA, 2007.
32. Goffman, E. Embarrassment and Social Organization. In *Interaction Ritual—Essays on Face-to-Face Behavior*; Aldine Transaction: Piscataway, NJ, USA, 1967; pp. 97–112.
33. Goffman, E. *The Presentation of Self in Everyday Life*; Doubleday: New York City, NY, USA, 1959.
34. Parsons, T. *The Social System*, 2nd ed.; Routledge: London, UK, 1991.
35. Giddens, A. *The Constitution of Society—Outline of the Theory of Structuration*, 1st ed.; Polity Press: Cambridge, UK, 1984.
36. Burghart, C.; Haeussling, R. Evaluation Criteria for Human Robot Interaction. In Proceedings of the Symposium on Robot Companions: Hard Problems and Open Challenges in Robot-Human Interaction, Hatfield, UK, 14–15 April 2005; pp. 23–31.

37. Ehrhardt, K.K.; Findeisen, P.; Marinello, P.; Reinartz-Wenzel, H. Systematische Verhaltensbeobachtung von Aufmerksamkeit bei Grundschülern während des Unterrichts. *Psychol. Erzieh. Unterr.* **1981**, *28*, 204–213. (In Germany)
38. Helmke, A.; Renkl, A. Das Münchener Aufmerksamkeitsinventar (MAI): Ein Instrument zur systematischen Verhaltensbeobachtung der Schüleraufmerksamkeit im Unterricht. *Diagnostika* **1992**, *38*, 130–141. (In Germany)