The Effects of Social Gaze in Human-Robot Collaborative Assembly

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Abstract. In this paper we explore how social gaze in an assembly robot affects how naïve users interact with it. In a controlled experimental study, 30 participants instructed an industrial robot to fetch parts needed to assemble a wooden toolbox. Participants either interacted with a robot employing a simple gaze following the movements of its own arm, or with a robot that follows its own movements during tasks, but which also gazes at the participant between instructions. Our qualitative and quantitative analyses show that people in the social gaze condition are significantly more quick to engage the robot, smile significantly more often, and can better account for where the robot is looking. In addition, we find people in the social gaze condition to feel more responsible for the task performance. We conclude that social gaze in assembly scenarios fulfills floor management functions and provides an indicator for the robot's affordance, yet that it does not influence likability, mutual interest and suspected competence of the robot.

Keywords: Human-robot interaction, gaze, conversation analysis, smile

1 Introduction

In this paper, we investigate the effects of gaze towards the human tutor in a human-robot assembly scenario. Previous work has shown that in social human-robot interactions, human-like gaze behavior in robots fulfills very similar functions as in interactions between humans (e.g. [1]). However, what roles social gaze behavior plays in

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industrial assembly tasks in general and in human-robot collaboration in particular has received much less attention. Employing social even in industrial scenarios may prove useful since naïve users are increasingly engaged in demonstrating novel actions to robots for industrial manufacturing [2]. We therefore carried out experiments in which the robot's gaze behavior differed between being fully instrumental to the assembly task (simple gaze condition) and focusing on the user between tasks (social gaze condition); in accordance with [1], we refer to the robot's gaze towards the human as social. The question we raise is which of the functions reported for social robots (e.g. [3,4]) and virtual agents (e.g. [5]) social gaze fulfills in this collaborative assembly situation.

2 Previous Work

Previous work on gaze in human interaction shows that it fulfills numerous important interactional functions. For instance, it serves to negotiate contact in first encounters and to establish an interpersonal relationship, including flirting [6]. Furthermore, gaze plays an important role in signaling attention during interaction; in particular, listeners have been found to attend to the current speaker by means of long gaze which is interrupted only by short glances away [7]. In teaching situations, students show higher performance if the teacher gazes at them [6]. Increased eye gaze has also been found to contribute to higher ratings of likability and mutual interest [6]. Gaze also plays a role in turn-taking, such that current speakers often gaze away when they want to keep the turn [7], while gazing towards the listener often elicits a response, either evoking feedback or selecting the next speaker [3].

Similarly, many of the functions of gaze observed in human interaction have been confirmed to be relevant for interactions with virtual agents (cf. [5] for an overview). That gaze fulfills these functions also in human-robot interaction has meanwhile been shown in numerous studies (e.g. [8], and [1] carry out a survey of previous work on gaze in human-robot interaction and suggest to systematize the social functions of gaze according to five main social contexts in which gaze plays a major role: establishing agency and liveliness; signaling social attention, for instance, by providing eye contact; regulating the interaction process, that is, facilitating turn-taking and supporting the participation framework; supporting interaction content, for instance, by disambiguating ambiguous information; and finally projecting mental state, in particular, expressing emotional or cognitive states. At the same time, it is equally important for the human, agent or robot to know when to avert gaze; for instance, [9] find that eye gaze may also be perceived as staring in virtual agents. Similarly, [10] show that gaze aversion supports floor management and creates the impression of higher cognitive capabilities and higher creativity of the robot.

On the other hand, gaze by robots has also been found to be not attended to in the same way as human gaze (e.g.[11,12]) or is not even taken into account because people may not look at the robot's face (e.g. [13,14,15]).

So far, it remains largely unexplored what functions an industrial robot's eye gaze might play during a collaborative assembly task. What previous work may predict is that the robot's gaze behavior can indicate what the robot is currently attending to and thus contribute to floor management and task organization; furthermore, the robot's gaze may influence the interpersonal relationship, making the robot appear more lively, more likeable, more cognitively competent and more socially attentive; and finally, the robot's gaze could also contribute to disambiguating information. However, whether robot gaze fulfills these functions also depends on whether participants attend to it and take it into account at all.

3 Method

In order to determine the role of social gaze in collaborative assembly tasks, we elicited 30 interactions between naïve users and an industrial robot in two conditions.

3.1 The Robot

The robot comprises two KuKa arms [16], each capable of seven degrees of freedom and each equipped with a Schunk 3-finger gripper. However, for this study the robot made only use of its left arm. The robot's KIT [17] head has cameras mounted in eyeballs and one Kinect camera on top. The robot was fully controlled remotely from a desk hidden from the participants. Our wizard was able to navigate using multiple cameras mounted on a steel frame above the workspace platform. An engineer oversaw the experiments to ensure the safety of both participants and robot.

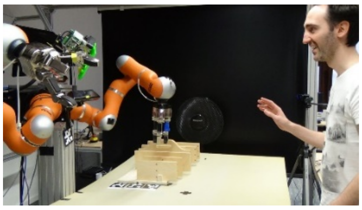


Fig. 1: Simple gaze

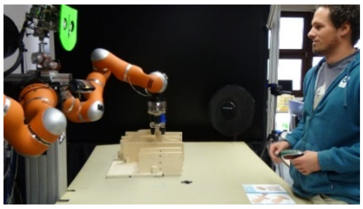


Fig. 2: Social gaze

3.2 Experimental Conditions

The study uses a between-subject design with two experimental conditions. In one condition, the robot's gaze follows its own hand (simple gaze). In the second condition (social gaze), the robot's face is initially directed at the participant, yet during tasks, the robot changes its gaze to its hand when it starts to move, and then looks to the user again when it has completed its task.

Given the rules defining the robot's gaze direction, the two conditions really only differ in two phases during the interaction: initially, when in the 'simple' gaze condition the robot's gaze is on its hand while it is on the user in the 'social' gaze condition, and during handover phases when the robot provides the user with the requested parts. While in the simple gaze condition the robot's gaze remains on its hand, in the social gaze condition the robot looks up at the user.

3.3 Experimental Procedure

Participants were led into the lab, where they signed a consent form, had their picture taken and were then introduced to the robot. The task was to guide the robot to assist them in assembling a wooden toolbox. They were told that the robot would be able to fetch the parts for them, but that they would need to instruct it to do so when appropriate and in whatever way that made sense to them; participants should then assemble the box on their own. Instructions were scripted so that all participants received the same information. After introducing the participants to the task, the facilitators did not intervene except when assisting users with the drill. Participants were led to believe that the robot acted autonomously, but it was in fact controlled using the Wizard-of-Oz technique. The human 'wizard' was instructed to react to gestures (e.g. pointing) and to ignore all other actions by the participants (e.g. speech). The 'wizard' had multiple cameras to observe the participants and to navigate the workspace. Due to the intranet, there was a slight delay for about one second between users' instruction and the robot's response. After participants completed the task, they filled out a questionnaire about their interaction with the robot.

3.4 Questionnaire

Based on previous findings regarding the influence of robot gaze on people's perception of the robot (e.g. [10]), the written questionnaire asked participants to rate how intelligent they perceived the robot to be, and to rate how safe they felt when interacting with the robot. The perceived intelligence and safety scales were adopted from [18]. This index proved relatively reliable (Cronbach's alpha for perceived intelligence / perceived safety of 0.67 / 0.94 in the simple gaze condition and 0.82 / 0.37 in the advanced gaze condition).

To determine to what extent people monitored the robot (cf. [15]), participants were then asked where the robot looked during their interaction, who was more responsible for task performance (10-point semantic differential), whether they thought the robot had learned from them (7-point likert scale), and who was most in control (human participant or robot on a 10-point semantic differential scale). Furthermore, participants were asked to rate to what extent they felt that they and the robot were a team on a 10-point likert scale, and what kind of communicative cues the robot provided them with.

3.5 Participants

We recruited 36 participants, who were all students or employees at the University of Innsbruck without prior experience with industrial robots. Participants were given chocolate as compensation for their time and participation. However, five participants were eliminated from analysis due to robot malfunction (overheating, security stops, etc.), and one was removed from the analysis in section 4.2 due to a deviant understanding of the initial instruction (see 4.2 below). Participant mean age is 23.7 (SD =

4.54). One-third of the participants were women, yet they were distributed evenly across the two experimental conditions.

3.6 Analysis

The focus of our investigation lies in participants' behavioral responses during their interaction with the robot. Our analyses were based on video recordings of the interactions, supplemented by field notes. Responses were coded and analyzed quantitatively, using single linear regression with the statistical software package R (v. 3.1.2), as well as qualitatively using ethnomethodological conversation analysis [19]. In particular, we asked 1) whether tutors looked at the robot and perceived the robot's gaze towards them (section 4.1), 2) what effects the robot's gaze towards the tutor has on conversational openings (section 4.2), 3) what effects robot gaze towards the human between tasks has (section 4.3), and 4) whether the robot's gaze behavior has an impact on tutors' perception of the robot's capabilities (section 4.4).

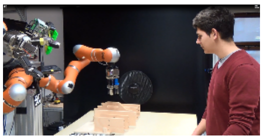
4 Results

4.1 Users' Perception of the Robot's Gaze Behavior

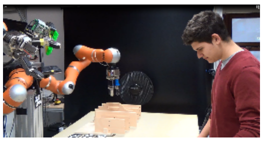
Before we look into the effects of robot gaze in the two conditions, we need to establish that participants actually perceived the robot's gaze. Here our analyses show that initially, all participants in the social gaze condition looked at the robot and perceived its gaze towards them. However, during the experiment, they often did not look up at the robot; in all, during 43 of the 90 handovers in the social gaze condition, the respective participant did not glance towards the robot. One participant looked at a time when the robot had not looked up yet, so he may have expected a different timing.

4.2 Eye Gaze during Contact Initiation

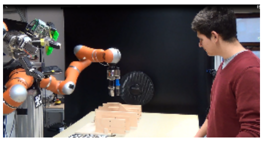
Participants in the social gaze condition needed less time to initiate their first action (instruction) than participants in the simple gaze condition. Using single linear regression, we find a statistically significant difference between participants in the simple gaze condition (M=37.39, SD=31.65) and the social gaze condition (M=11.96, SD=14.6), $F(1,28) = 8.37$, $p = 0.007$, $R^2=0.24$ (measurements are in number of seconds). We find no significant results on age or gender as predictor variables and no significant interactions. Using visual inspection of boxplots, we eliminated one extreme outlier from the analysis; this participant repeatedly directed his attention to the experimenter to ask specifically about how the robot was built and what components were used in its assembly, thus not engaging with the robot at all. Otherwise, we can see very different ways of approaching the robot in the two conditions, as the following two examples illustrate: The example in Fig. 3 stems from the simple gaze condition and illustrates how the participant hesitates and is clearly uncertain about how the robot can be approached. The example in Fig. 4, in contrast, shows how a participant in the social gaze condition straight-forwardly approaches the robot by establishing mutual eye-gaze, waving and smiling.



User looks at the

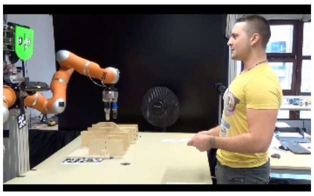


User looks down

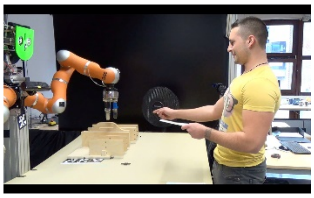


User looks at the robot

Fig. 3: Participant does not know how to start



User meets the robots gaze

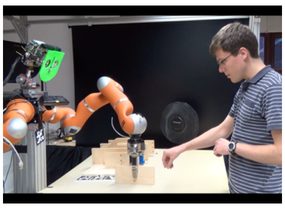


User says “Hello robot, give me piece #1”

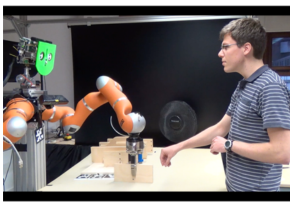
Fig. 4: Participant takes robot gaze as a sign for mutual attention

4.3 Eye Gaze between Tasks

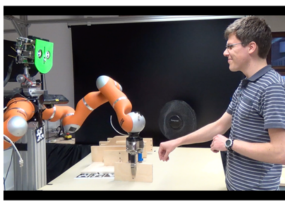
The example in Fig. 5 below shows how the robot’s eye gaze is understood as a straightforward social signal by the participant and is met with mutual eye gaze and a spontaneous smile. In 75.6% of the cases in which users looked up to see the robot’s eye gaze, they responded to the robot’s gaze with a smile. Correspondingly, the numbers of smiles between simple gaze (M=3.47, SD=1.92) and social gaze (M=5.13, SD=2.33) conditions is significantly different: $F(1,28) = 4.58$, $p = 0.04$, $R^2=0.14$.



Robot and user look up

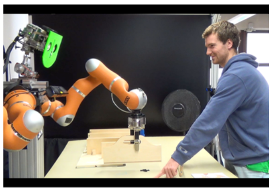


User looks at robot

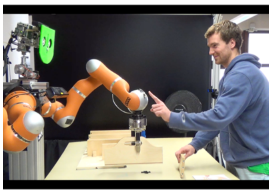


User starts smiling

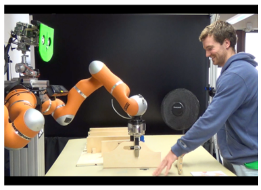
Fig. 5: Spontaneous smile in response to mutual gaze



Robot and user look up



User raises finger



User instructs robot

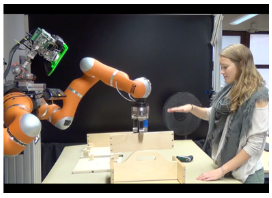
Fig. 6: User directs the robot's gaze back to his hand

However, some participants also try to draw the robot's attention back to their hands when the robot directs its gaze towards them, as in Fig. 6 where the participant first reciprocates the robot's gaze smilingly, yet then lifts up his hand to direct the robot's gaze back to the instruction.

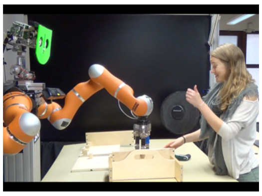
4.4 Conceptualizing the Robot and Understanding Robot Gaze

In a post-experimental questionnaire, we asked participants about how intelligent, safe, teachable and compliant they perceived the robot to be; regarding none of these measures there are any statistically significant differences between the two conditions. Furthermore, the two groups do not differ regarding their feeling of them building a team with the robot.

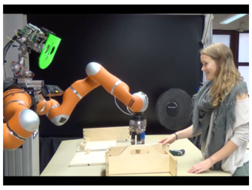
Regarding the question of who participants thought was most responsible for the performance of that task (1=robot, 10=participant), we find a statistically significant difference between the simple gaze condition (M=6.93, SD=2.13) and the social gaze condition (M=8.24, SD=1.25), $F (1, 29) = 4.53$, $p = 0.04$, $r^2=0.14$, such that tutors in the social gaze condition thought that the tutors themselves were more responsible for performance of the task than the tutors in the simple gaze condition thought.



User says: "and now down"



Robot looks up. User looks up, says "perfect"



User takes piece and smiles

Fig. 7: Robot's social gaze as invitation for feedback

We also inquired into participants' understanding of the robot's gaze behavior. In the simple gaze conditions, seven tutors stated that the robot's gaze served as a communicative cue, while two held the robot to move in response to his/her own movements, and five did not know or identify any cues. In contrast, 15 participants in the social gaze condition identified the robot's gaze as a communicative cue, while only two did not know or could not identify any communicative cues. This difference was found statistically significant ($p<0.05$), using Fisher's exact test. The qualitative analysis of the handovers furthermore shows that participants interpret the robot's gaze towards them as an invitation to provide feedback, as Fig. 7 illustrates.

Finally, we asked whether participants could tell where the robot was looking. For the simple gaze condition, one participant could correctly tell that the robot was constantly looking at its own arm, nine participants made incorrect guesses as to where the robot was looking, three simply stated that they could not infer the robot's gaze and one answered the question with a simple 'yes' without further elaboration. For the social gaze condition, 12 could correctly tell that the robot looked at them, then at its own arm and then again at them, four made incorrect guesses, and one answered the question with a simple 'yes' without any further elaboration. These differences were also found statistically significant ($p<0.01$) using Fisher's exact test.

5 Discussion

In all, we found users to take the robot's gaze behavior into account initially as well as during approx. 50% of the handovers. Given that the robot's gaze towards the users was purely social and did not serve any disambiguating or other task-related functions, this percentage is very high in comparison with previous work (e.g.[15]), and our questionnaire results show that participants understood the robot's gaze towards them as intentional signs. Furthermore, there is evidence for a role of the robot's social gaze in floor management and participation framework (cf. [3]) since participants responded to the robot's gaze in handovers as a request for feedback (Fig. 7). Similarly, the finding that people in the social gaze condition feel more responsible for the performance than people in the simple gaze condition is most likely due to the fact that in the social gaze condition, the robot seemingly awaits instructions each time it finishes a task and thus provides a turn-yielding signal. As a result, participants in the social gaze condition feel to a greater extent that the performance of the task is contingent on their ability to instruct the robot.

As for interpersonal functions concerning intimacy and relationship negotiation, we find on the one hand that participants in the social gaze condition generally found it easier to make contact with the robot than participants in the simple gaze condition, as the reduced contact initiation times show; obviously, they felt they knew how to interact with it. Thus, participants in the social gaze condition were found to engage with the robot sooner than participants in the simple gaze condition. On the other hand, we found that the robot's social gaze behavior had no influence on users' perception of the robot's cognitive capabilities, compliance, learning and safety in general. This is unexpected for several reasons: First, previous work had shown that correctly timed eye gaze creates the impression of higher cognitive ability [10]; now it could be argued that the robot's gaze may not have been timed appropriately. However, while it may not have respected human-like gaze patterns during handovers (cf. [8, 20]), it did mark the difference between different phases of the collaborative assembly, namely delivering a part versus awaiting another instruction. Second, participants in the social gaze condition were found to smile at the robot more often, which could have led to a more intimate interpersonal relationship and perceived tighter teamwork.

Thus, gaze towards the user does not automatically create rapport. At the same time, there are no indications that participants found the robot to 'stare' even though it was looking in their direction while participants were busy assembling the toolbox; on the contrary, participants turned to the robot smilingly when they finished their (solitary) assembly phases (cf. [21]). Thus, the robot's gaze towards participants seems to be perceived not as social enough to be perceived as staring and not as social enough to change users' general view of the robot, yet as social enough to be met with a smile.

6 Conclusion

To conclude, allowing the user to establish mutual eye gaze during the initiation of interaction by having the robot look towards the participant does not only serve 'to break the ice' [22], but also provides users with a necessary indicator of the robot's "entry point" for the interaction since people interacting with the robot in the social gaze condition are significantly quicker to engage the robot. Thus, an important function of social gaze in collaborations with assembly robots is to provide an indicator for how the robot can be interacted with. This function of social gaze has not been reported for robot gaze, most likely because it is not relevant in human interaction.

Furthermore, participants in the social gaze condition smile significantly more often and can better account for where the robot is looking compared to participants in the simple gaze condition. In addition, we also found that people in the social gaze condition feel more responsible for the task performance. These findings support previous work on gaze by social robots concerning floor management, which turns out particularly useful during assembly tasks as indicator for turn-yielding during handovers, yet they are inconclusive regarding the interpersonal impact of robot social gaze.

7 Acknowledgements

This research was partially funded by the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement no. 610878, 3rdHAND.

8 References

1. Srinivasan, V & Murphy, R.R. (2011). A Survey of Social Gaze. *Proceedings of HRI'11*, Lausanne, Switzerland.
2. Muxfeldt, A., Kluth, J.-H. and Kubus, D. 2014. Kinesthetic Teaching in Assembly Operations – A User Study. Brugali, D. et al. (eds.), SIMPA 2014, LNAI 8810, pp. 533-544.
3. Mutlu, B., Kanda, T., Forlizzi, J., Hodgins, J., & Ishiguro, H. (2012). Conversational Gaze Mechanisms for Humanlike Robots. *ACM Transactions on Interactive Intelligent Systems* 1, 2, art. 12.
4. Moon, A., Troniak, D. M., Gleeson, B., Pan, M. K., Zeng, M., Blumer, B. A., MacLean, K., & Croft, E. A. (2014). Meet me where I'm gazing: how shared attention gaze affects human-robot handover timing. In *Proceedings of HRI'14*, 334–341.

5. Ruhland, K., Andrist, S., Badler, J.B., Peters, C.E., Badler, N.I., Gleicher, M., Mutlu, B., & McDonnell, R. (2014). Look me in the eyes: A survey of eye and gaze animation for virtual agents and artificial systems. In *Eurographics 2014*.
6. Argyle,M. & Cook, M. (1976). *Gaze and Mutual Gaze*. Cambridge University Press.
7. Kendon, A. (1990). *Conducting Interaction: Patterns of Behavior in Focused Encounters*. Cambridge University Press.
8. Mehlmann, G., Häring, M., Janowski, K., Baur, T., Gebhard, P. & André, E. 2014. Exploring a Model of Gaze for Grounding in Multimodal HRI. *ICMI 2014*: 247-254.
9. Wang, N. & Gratch, J. (2010). Don't just Stare at me! *Proceedings of CHI 2010*, Atlanta, Georgia, USA.
10. Andrist, S., Tan, X.Z., Gleicher, M. & Mutlu, B. (2014). Conversational Gaze Aversion for Humanlike Robots. *Proceedings of HRI'14,* Bielefeld, Germany.
11. Admoni, H., Bank, C., Tan, J., Toneva, M., & Scassellati, B. (2011). Robot gaze does not reflexively cue human attention. *Proceedings of the 33rd Annual Conference of the Cognitive Science Society (CogSci 2011)*, pp.1983-1988. Austin, TX.
12. Meltzoff, A. N., R. Brooks, A. P. Shon, and R. P. Rao (2010). "Social" robots are psychological agents for infants: A test of gaze following. *Neural Networks* 23, 966–972.
13. Fischer, K., Lohan, K., Nehaniv, C. & Lehmann, H. (2013). Effects of Different Types of Robot Feedback. *International Conference on Social Robotics'13,* Bristol, UK.
14. Fischer, K., Soto, B., Pantofaru, C. & Takayama, L. (2014). The Effects of Social Framing on People's Responses to Robots' Requests for Help**.** *Proceedings of the IEEE Conference on Robot-Human Interactive Communication – Ro-man '14,* Edinburgh.
15. Admoni, H., Dragan, A., Srinivasa, S.S, & Scassellati, B. (2014). Deliberate Delays During Robot-to-Human Handovers Improve Compliance With Gaze Communication. *Proceedings of HRI'14*, Bielefeld, Germany.
16. Bischoff, R., Kurth, J., Schreiber, G., Koeppe, R., Albu-Schäffer, A., Beyer, A., Eiberger, O., Haddadin, S., Stemmer, A., Grunwald, G. & Hirzinger, G. (2010). The KUKA-DLR Lightweight Robot arm - a new reference platform for robotics research and manufacturing. In *ISR-Robotik (2010), Joint 41st International Symposium on Robotics and 6th German Conference on Robotics,* Munich, pp. 741-748.
17. Asfour, T., Welke, K., Azad, P., Ude, A., & Dillmann, R. (2008). The Karlsruhe humanoid head. In 8th IEEE-RAS International Conference on Humanoid Robots, pp. 447-453.
18. Bartneck, C., Croft, E., & Kulic, D. (2009). Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. *International Journal of Social Robotics*, 1(1), 71-81.
19. Sacks, H., E. A. Schegloff, and G. Jefferson (1974). A simplest systematics for the organization of turn-taking for conversation. *Language* 50 (4), 696–735.
20. Strabala, K., Lee, K., Dragan, A., Forlizzi, J., Srinivasa, S., Cakmak, M. & Micelli, V. (2013). Toward Seamless Human-Robot Handovers. *Journal of Human-Robot Interaction* 2(1):112–132, 2013.
21. Kirstein, F., Fischer, K., Erkent, Ö. and Piater, J. (2015). Human Smile Distinguishes between Collaborative and Solitary Tasks in Human-Robot Interaction. *Late Breaking Results*, *Human-Robot Interaction Conference 2015*, Portland, Oregon.
22. Bee, N., André, E. & Tober, S. (2009). Breaking the Ice in Human-Agent Communication: Eye-Gaze Based Initiation of Contact with an Embodied Conversational Agent. In Zs. Ruttkay et al (eds.), *Intelligent Virtual Agents 2009*, pp. 229-242. Berlin/Heidelberg: Springer.