Effects of Cognitive Load Variation on Anthropomorphism During a Cooperative Human-Robot Pick-and-Place Task

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Abstract: This paper investigates anthropomorphism of a robot arm during a cooperative human-robot pick-and-place task, while varying cognitive load of test persons. Test persons are required to repeatedly provide a Lego brick for the robot by alternatingly putting it onto one of two trays. The robot then picks it up and puts it in front of the test person again. Cognitive load is varied by whether or not an initially given 8-digit number has to be remembered by the test person. Dimensions of anthropomorphism are acquired using the HRIES questionnaire and cognitive load is acquired using two state-of-the-art questionnaires. Results show a significant correlation of perceived sociability and animacy on mental demand and cognitive load, but only in the high load condition. It is suggested, that cognitive load should be considered during cooperative task design because resulting variations of anthropomorphism may impact cooperative task performance.

1 INTRODUCTION

Human-like form and function can increasingly be noted in many robotic products. Especially, in the field of industrial robots, this is an interesting trend (e.g. Sawyer (ReThink Robotics), YUMI (ABB), etc.). Intuitiveness of how to interact with the robot is one reason (Mayer et al., 2012), e.g. in terms of predictability and legibility of actions (Brecher et al., 2013; Kirsch et al., 2010). It is further assumed, that still human workers will be required in many production environments, e.g. for particular tasks in the area of assembly (Faber et al., 2015), where flexibility, cognitive abilities and sensorimotor skills of the collaborating human is complemented by endurance and power of the robot (Shen and Reinhart, 2013). Further, the ongoing trend towards small batch sizes is difficult to be accounted for by many SMEs in terms of complete automation of production lines, which may be uneconomical (Bley et al., 2004). In this context, Challenges and potential contribution of collaboration of human and robot in manufacturing are recognized especially for high-wage countries (Petruck et al., 2016).

The effect of anthropomorphism, i.e. attributing human-like qualities to an object, is therefore important to be accounted for in human-robot interactive collaboration as it is known to impact collaborative task-performance as well as user experience. However, it is also known, that cognitive load has a significant effect on anthropomorphism (Spatola and Chaminade, 2022), whereas higher cognitive load leads to increased levels of anthropomorphism as two main processes co-exist in the human brain concerning social and physical cognition with the social pathway being the default of cognitive process-sing, e.g. (Mars et al., 2012). Social cognition is further related to attributing socially relevant parameters, e.g. anthropomorphism. This default pathway, however, may be inhibited by processes, which are concerned with physical tasks (Darlow and Sloman, 2010; Evans and Stanovich, 2013). So far, however, this effect is not yet investigated within physical human-robot interaction contexts as in related work, only robot videos are

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displayed without any physical task to be accomplished by the participants (Spatola and Chaminade, 2022).

Furthermore, also adverse effects are present, which result from human-like design of robots. In this context, it is known from human-human interaction, that hand movements may deviate from task movements in the direction of the hand movements of a counterpart, which is also found to be present in human-robot interaction (Kilner et al., 2003; Chaminade et al., 2005; Kühnlenz and Kühnlenz, 2020; Kupferberg et al., 2011) and which is assumed to be caused by activation of the mirror neuron system and the implication of a tendency to imitate a human counterpart to some extent. Also here, the effect of anthropomorphism of robots may be highly relevant.

This paper investigates, in how far cognitive load affects anthropomorphism during a real cooperative human and robot pick-and-place task. An object placement scenario is chosen, where robot and human are positioned in front of and facing each other and test persons have to repeatedly place an object alternatingly on a left and right tray to be picked up by the robot, which puts it back to an initial tray.

The remainder of the paper is organized as follows: In Section 2, the hypothesis and study design are presented; results are shown in Section 3 and discussed in Section 4; conclusions are given in Section 5.

2 HYPOTHESES

As outlined, a significant dependency of anthropomorphism dimensions on cognitive load is expected as well as a positive association of both during a physical human-robot cooperation task. So, the main hypotheses are:

H1: Anthropomorphism of a robot depends on cognitive load during physical cooperation of human and robot.

H2: Anthropomorphism and cognitive load are correlated positively during physical cooperation of human and robot.

3 METHODOLOGY

In this paper, we exemplarily explore the effect of cognitive load of a test person on anthropomorphism of a cooperating robot. A cooperative pick-and-place task was chosen, where the test person has to place a Lego brick on one of two trays in an alternating way, whereafter a Panda robot arm (Franka Emika) repeatedly put the Lego brick back to an initial position, where it is picked up then again by the test person. Two randomized conditions (counterbalanced, low load vs. high load) are realized as independent factor variable in a within-subjects design, which differ in whether an additional mental task has to be performed constituting a certain additional cognitive load for the test person.

Induction methodologies for cognitive load are manifold, whereas three main techniques are commonly used: number memorization, visual pattern and auditory recall tasks, and time pressure (Deck et al., 2021). Due to practical reasons in the context of the chosen scenario, we decided for number memorization, where the test person is shown an 8-digit number, which they are told to memorize during the task and write down afterwards.

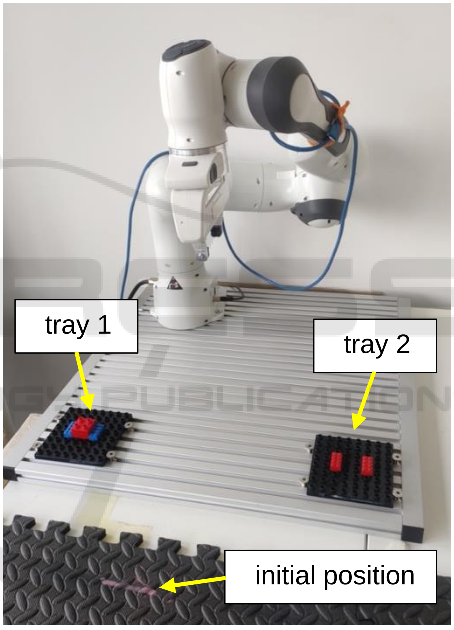

Figure 1: Experimental set-up.

Initially, test persons are briefed towards the experimental procedure, but not the hypotheses, and informed consent is obtained. The persons then have to complete a pre-questionnaire acquiring demographic data (age, gender), previous experience with robots, field of study, and left-/right-handedness. Afterwards the cooperation task is performed in each of the two cognitive load conditions in randomized way, whereas a post-questionnaire is completed after each condition. Finally, a de-briefing is conducted.

The post-questionnaire acquires dimensions of perceived anthropomorphism as well as task-load based on the validated Human-robot Interaction Evaluation Scale HRIES (4 constructs (sociability, animacy, agency, disturbance) of 4 items each, 7-point Likert scale) (Spatola et al., 2021), and NASA TLX (5-point Likert-scale), respectively. In the latter, the sub-scale 'mental demand' is assumed to be correlated with cognitive task load. In addition, another construct for cognitive load measurement is used in order to be comparable to (Spatola and Chaminade, 2022), which includes the two questions "*Regarding the task you performed, the task was very complex*" and "*Regarding the task you performed, you provided a very high mental effort to solve it*". For reasons of clarity, this measure is abbreviated 'CL' in the following.

The procedure for one test person is shown in Table 1.

Table 1: Procedure for one test person.

Task	duration	comments
briefing		introduction (context, procedure, tests)
PRE-quest.	~2 min	demographic data, previous experience
set-up		place test person
adjust	~1 min	let person adjust to setting
cond. 1	~1 min	object placement task in condition 1
POST-quest.	~2 min	NASA TLX, CL, HRIES
cond. 2	~1 min	object placement task in condition 2
POST-quest.	~2 min	NASA TLX, CL, HRIES
de-briefing		

4 RESULTS

Results are obtained from 32 test persons (age between 20 and 42 years, M = 25.3y, SD = 5.8y) and 64 trials (32x2 conditions in a within-subjects design). All participants are right-handed.

Analyses of covariance (ANCOVA) are conducted with the HRIES constructs of anthropomorphism dimensions sociability, animacy, agency, and disturbance as dependent variables and NASA TLX and cognitive load items, respectively, constructs as covariates. Q-Q plots of standardized residuals show only slightly skewed data with few outliers, so it is assumed, that ANCOVA results are sufficiently reliable, in order to obtain conclusive results.

In the high cognitive load condition, ANCOVA results of sociability with respect to NASA TLX mental demand and cognitive load construct show a significant dependency (see Table 2) with a positive association of both (see Fig. 2). For the remaining NASA TLX items, no significant effect is observed.

Similarly, ANCOVA results of animacy with respect to cognitive load construct show a significant dependency (see Table 3) with a positive association of both (see Fig. 3). For the NASA TLX items, however, no significant effect is observed.

For the remaining, HRIES constructs of anthropomorphism (agency and disturbance) no significant effects are obtained.

In the low cognitive load condition, no significant effects are observed.

Table 2: ANCOVA results in high cognitive load condition; sociability with respect to NASA TLX mental demand and cognitive load construct (CL).

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
CL	17.659	1.000	17.659	11.262	0.002	0.280
mental demand	7.886	1.000	7.886	5.029	0.033	0.148
Residual	45.475	29.000	1.568			

Note. Type III Sum of Squares

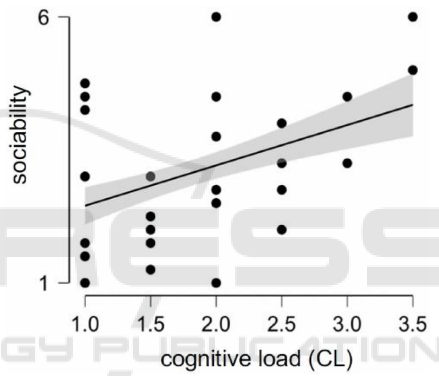

Figure 2: Regression of sociability and cognitive load; standard error.

Table 3: ANCOVA results in high cognitive load condition; animacy with respect to NASA TLX mental demand and cognitive load construct (CL).

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
CL	7.076	1.000	7.076	4.625	0.040	0.138
mental demand	1.914	1.000	1.914	1.251	0.273	0.041
Residual	44.374	29.000	1.530			

Note. Type III Sum of Squares

Table 4: Wilcoxon test results of cognitive load construct (CL) in the low- (CL(L)) and high-load (CL(H)) conditions.

			W	p	Rank-Biserial Correlation
CL(L)	-	CL(H)	32.500	0.010	-0.658

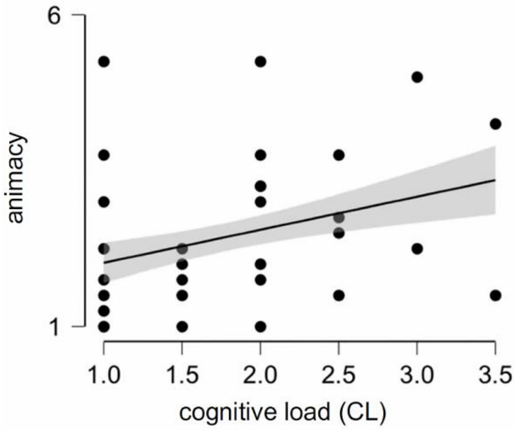

Figure 3: Regression of animacy and cognitive load; standard error.

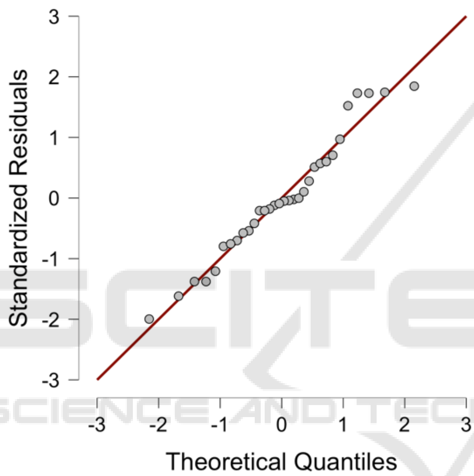

Figure 4: Q-Q plot; ANCOVA of sociability dependend on cognitive load (CL).

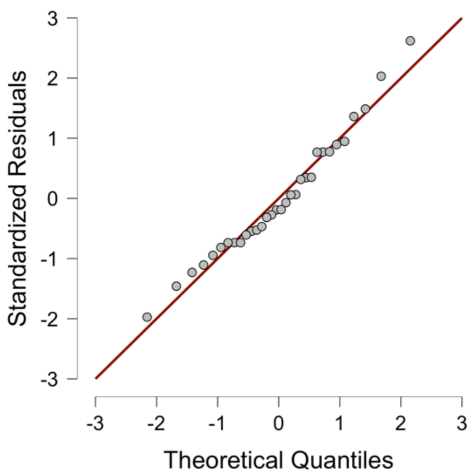

Figure 5: Q-Q plot; ANCOVA of animacy dependend on cognitive load (CL).

With respect to checking, whether a different cognitive load is induced in the two conditions a Wilcoxon signed-rank test is conducted showing a significant difference of cognitive load with a strong effect (see Table 4 and Figure 6).

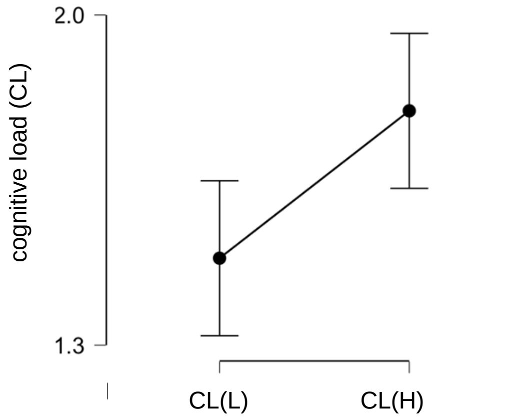

Figure 6: Cognitive load (CL) in low- (CL(L)) and high-load (CL(H)) conditions.

Finally, in order to check for the association of the NASA TLX mental demand scale and cognitive load (CL) construct scale, a correlation analysis shows a moderate positive association ($p = 0.006$, $r = 0.48$).

5 DISCUSSION

The expected significant positive association between dimensions of anthropomorphism and cognitive load could be confirmed with respect to constructs of sociability and animacy, supporting H1 and H2. However, this effect is limited to the high cognitive load condition. In the low cognitive load condition, such an association is not observed. This phenomenon could be grounded in a larger variance in the low cognitive load condition compared to the high cognitive load condition due to no particular cognitive load induction is performed in the former. It would be interesting to investigate the effects using cognitive load induction in both conditions on different levels of difficulty.

Effects are of small to moderate strengths (see Tables 2 and 3), which could be related to the induced cognitive load differences are also relatively small (see Table 4 and Figure 6). Stronger effects might be achieved with larger induced load differences.

Insignificant results regarding agency could be related to the construct being less suited to evaluate a robot arm as it refers to perceiving the robot as an agent as a person having its own beliefs, thoughts and intents (Spatola and Chaminade, 2022). Regarding the disturbance construct, the authors themselves argue, that the scale is more ambiguous than the others, which could result in larger variance in the scenario at hand.

Limitations are given by the moderate sample size and single interaction task and robot design. More test persons and different interaction scenarios may contribute to increase the effects and generalize the findings.

6 CONCLUSIONS

In the presented human-robot cooperative pick-and-place study, induction of cognitive load contributed to a significant positive association of the anthropomorphism dimensions sociability and animacy with experienced mental demand and cognitive load of the test persons. Variable strength of anthropomorphism due to cognitive load variation may influence cooperative task performance, which is generally dependent on the level of perceived human-likeness of a robot in manifold ways and thus may impact human-robot interaction quality in a variety of application scenarios.

Future work will target additional aspects, which might result from different levels of anthropomorphism due to cognitive load variation in the context of safety and trust.

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REFERENCES

Mayer, M., Odenthal, B., Ewert, D., Kempf, T., Behnen, D., Bücher, C., Kuz, S., Hauck, E., Kausch, B., Schilberg, D., Herfs, W., Schlick, C., Jeschke, S. and Brecher, C. (2012). "Self-optimising assembly systems based on cognitive technologies," in *Integrative Production Technology for High-Wage Countries*, C. Brecher, Ed. Springer, pp. 877–990.

Brecher, C., Müller, S., Kuz, S. and Lohse, W. (2013). "Towards anthropomorphic movements for industrial robots, likeability, perceived intelli- gence, and perceived safety of robots," *Proc. 4th Int. Conf. Digit. Hum. Modeling and Applic in Health, Saf., Erg., and Risk Man*.

Kirsch, A., Kruse, T., Sisbot, A., Alami, R., Lawitzky, M., Brscic´, D., Hirche, S., Basili, P. and Glasauer, S. (2010). "Plan-based control of joint human-robot activities," *KI, 24(3):*223–231.

Faber, M., Bützler, J. and Schlick, C. (2015). "Human-robot cooperation in future production systems: Analysis of requirements for designing an ergonomic work system," *Procedia Manufacturing*, vol. 3, pp. 510– 517.

Shen, Y. and Reinhart, G. (2013). "Safe assembly motion - a novel approach for applying human-robot co-operation in hybrid assembly systems," in *Proc. IEEE ICMA*.

Bley, H., Reinhart, G., Seliger, G., Bernardi, M. and Korne, T. (2004). "Appropriate human involvement in assembly and disassembly," *CIRP Annals - Man. Tech., Elsevier*,53:487–509,2004.

Petruck, H., Kuz, S., Mertens, A. and Schlick, C. (2016). *Increasing Safety in Human-Robot Collaboration by Using Anthropomorphic Speed Profiles of Robot Movements*.

Spatola, N. and Chaminade, T. (2022). Cognitive load increases anthropomorphism of humanoid robot. The automatic path of anthropomorphism, International Journal of Human-Computer Studies, Volume 167.

Mars, R. B., Neubert, F. X., Noonan, M. A. P., Sallet, J., Toni, I., Rushworth, M. F. S. (2012). On the relationship between the "default mode network" and the "social brain." Front. Hum. Neurosci., 6, pp. 1-9.

Darlow, A. L., Sloman, S. A. (2010). Two systems of reasoning: architecture and relation to emotion. Wiley Interdisciplinary Reviews: Cognitive Science, 1, pp. 382-392.

Evans, J. S. B. T., Stanovich, K. E. (2013). Dual-process theories of higher cognition: advancing the debate. Perspect. Psycholog. Sci., 8 (3), pp. 223-241.

Kilner, J., Paulignan, Y. and Blakemore, S. (2003). "An interference effect of observed biological movement on action," *Current Biology*, vol. 13, no. 6, pp. 522–525.

Chaminade, T., Franklin, D., Oztop, E. and Cheng, G. (2005). "Motor interference between humans and humanoid robots: Effect of biological and artificial motion," *Proc. IEEE ICDL*.

Kühnlenz, K. and Kühnlenz, B. (2020). "Motor interference of incongruent motions increases workload in close HRI," *Advanced Robotics*, vol. 34, no. 6, p. 400–406.

Kupferberg, A., Glasauer, S., Huber, M., Rickert, M., Knoll, A. and Brandt, T. (2011). "Biological movement increases acceptance of humanoid robots as human partners in motor interaction," *AI & Society*, vol. 26, no. 4, pp. 339–345.

Spatola, N., Kühnlenz, B., Cheng, G. (2021). Perception and evaluation in human–robot interaction: The human–robot interaction evaluation scale (HRIES)—a multicomponent approach of anthropomorphism. International Journal of Social Robotics, 13(7), pp. 1517-1539.

Deck, C., Jahedi, S. and Sheremeta, R. (2021). On the consistency of cognitive load, European Economic Review, Volume 134.