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Perceived autonomy in assembly

What is the effect of collaboration between operator and cobot?

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Perceived autonomy in assembly: What is the effect of collaboration between operator and cobot?

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Preface - Mentech and AMS

The study described in this thesis has been executed in the name of Mentech as part of a larger project towards the exploration of an Affective Manufacturing System (AMS). This project has been executed in collaboration by Mentech and Tegema with financial support of the Trinity project. Tegema has provided their expertise on production performance and optimization. In combination, Mentech provided their expertise on stress and emotion detection shaping the affective aspect. In short, the goal of AMS is to improve the safety and performance of an employee by incorporating affective strategies. Such strategies are based on the live performance and stress of the employee. A collaborative robot, or so to say, a cobot, can be deployed as strategy to take over, for instance, a complex assembly step to relieve the employee of that task as stressor. This study has contributed to a better understanding of the cobot application as affective strategy.

I would like to express my gratitude to Mentech for the opportunity and support. In specific, I would like to thank my supervisor at Mentech, R. Smits along with my colleagues who contributed to the AMS project. They have supported me during this study with valuable insights, feedback and assistance.

Lastly, for the supervision from the TU/e I would like to thank my first supervisor J.R.C. Ham and second supervisor R.H. Cuijpers for their feedback, effort and academic guidance.

Abstract

Robot collaboration (e.g., cobots) has become an increasingly more promising domain for optimizing performance and human-technology integration within the industry. Until now, it has been unclear how different degrees of cobot autonomy influence the human's perceived task autonomy in the collaboration. The present work builds on the Self-Determination Theory as a framework for work motivation and addresses the perceived task autonomy accordingly. In an experimental 2 x 2 within-subject design, the psychological and physiological effects of varying levels of autonomous functioning by a robot in an assembly collaboration have been investigated. The factors perceived task autonomy, perceived control, task enjoyment, and stress levels are examined over a sample of $N = 26$ participants. It was found that participants experienced a significant decrease in the first three factors when collaborating with a high autonomy cobot and vice versa for a low autonomy cobot. The variation in degrees of cobot autonomy showed no effect on the observed stress levels. The present work is the first, to our knowledge, to have investigated this relation within robot collaboration. The results emphasize the importance of the human perspective when collaborating with autonomous robots, as this might improve the potential of collaboration with autonomous artificial agents.

Keywords: cobot, human-robot interaction, perceived autonomy, I4.0

Contents

List of Figures and Tables

1 Introduction

In the present day, technological development has become a constant in most human activities. Major steps are made in production automation in industry, effectively causing the fourth industrial revolution called Industry 4.0 (I4.0) (Galin et al., 2020). Collaborative Robots [Cobots] are one of the I4.0 application examples and are increasingly deployed (Cohen et al., 2021). The assembly domain is particularly appealing for cobot integration since the investment is justified by the expected increase in output (Cohen et al., 2019). More precisely, fully automating assembly with robots creates costs, often overreaching the financial benefits (Wang et al., 2019). Human-robot collaboration improves manufacturing performance because of the combined and complementary abilities (Wang et al., 2019). For example, a cobot could assist inexperienced workers during assembly or replace an absent employee taking the position as a coworker (Cohen et al., 2021). Of essence is the motivation amongst workers to collaborate with a cobot. As the cobot takes over some of the work in the shared productive process, the cobot will become an independent entity to a certain degree. As a result, the worker might experience a loss of perceived job or task autonomy, which may ultimately lead to, for instance, lower work motivation and satisfaction. Therefore, the current research will investigate the relationship between the perceived task autonomy level of the collaborating worker and the actual autonomy level of a cobot. This introduction will present a general overview of the relevant literature, followed by a concise account of the Self Determination Theory of behavior motivation. Next, an elaboration on the cobot itself will be presented, discussing the differences with robots, the taxonomy of collaboration, and the explanation of cobot autonomy. Finally, this Introduction will cover the need for autonomy amongst assembly workers followed by a brief description of this study with the hypotheses and research question.

The amount of research addressing cobot integration in the industry has seen a clear upwards trend (Dobra & Dhir, 2020; Hentout et al., 2019; Vicentini, 2021). Literature reviews show that several topics are addressed in research like hardware and software, safety, task allocation, communication, and organizational considerations (Dobra & Dhir, 2020; Hentout et al., 2019; Vicentini, 2021). According to Vicentini (2021), most research focuses on the performance metric inherent to the collaboration, like role assignment or optimized task allocation.

However, the human factor remains underexamined for cobots integration and I4.0 in general (Neumann et al., 2021; Vicentini, 2021). Neumann and colleagues (2021) explain that dimensions like job satisfaction, job control, and coworker support are crucial to the psychosocial working environment. Moreover, the success of socio-technical systems like cobots is dependent on the quality of the psychosocial working environment.

Since the cobot will be actively present in the working environment, the motivation to collaborate with robots starts with the right attitude towards the interaction. Rather, this can be observed as a point of uncertainty within the industry. For example, Gnambs and Appel (2019) indicate an increasingly more cautious stance towards using autonomous robotic systems in Europe perceived over the years between 2012 and 2017. More specifically, they explain that the trend does not deviate from the domain of robots in the working environment, arguably inducing an increasingly negative attitude towards robots. The outcome of the Model of Autonomous Technology Threat by Stein and colleagues (2019) can contribute to the negative stance. The authors explain that people perceive autonomous technologies as more threatening, specifically to one's safety, identity and control. Considering the introduction of cobots in human-robot interaction, Kopp et al. (2020) present in their empirical framework that the fear of losing one's job to cobots is an important limiting factor. In line with that, Latikka et al. (2021) present in their study a comparable cautious perception towards cobot implementation in the industry. When considering the degree of automation, the authors mentioned a more positive attitude towards nonautonomous robots than autonomous robots. Respectively, robots as equipment are more positively perceived than robots as a coworker.

Importantly, in a working environment like I4.0, Self Determination Theory helps us understand the motivation for behavior. According to the Self Determination Theory, an individual's social environment is an essential facilitator for engaging behavior under the right circumstances (Deci & Ryan, 2000). Namely, the theory postulates three psychological needs - relatedness, competence, and autonomy - either supported or unsupported by the social environment. When these needs are satisfied, they enhance self-regulation, well-being, and intrinsic motivation, effectively fostering the willingness to engage in a behavior. Logically, when these needs are not supported or thwarted by the social environment, well-being is negatively impacted.

Motivation found in the social environment can be distinguished in two types (Gagné & Deci, 2005): Extrinsic motivation and intrinsic motivation. Extrinsic motivation is induced or controlled by someone or something else relying on external rewards or pressure. Intrinsic motivation is induced by the self, satisfying internal rewards involving the enjoyment or interest in behavior. An extrinsic motivator can overrule intrinsic motivation, meaning that innate motivation became controlled by external rewards. Being controlled causes a decrease in the satisfaction of the basic psychological needs, consequently negatively affecting the motivation for behavior. On the other hand, autonomous motivation can only be achieved when the need for autonomy is satisfied. Specifically, autonomy is facilitated by volition, freedom from too much external pressure towards behavior, and the experience of choice.

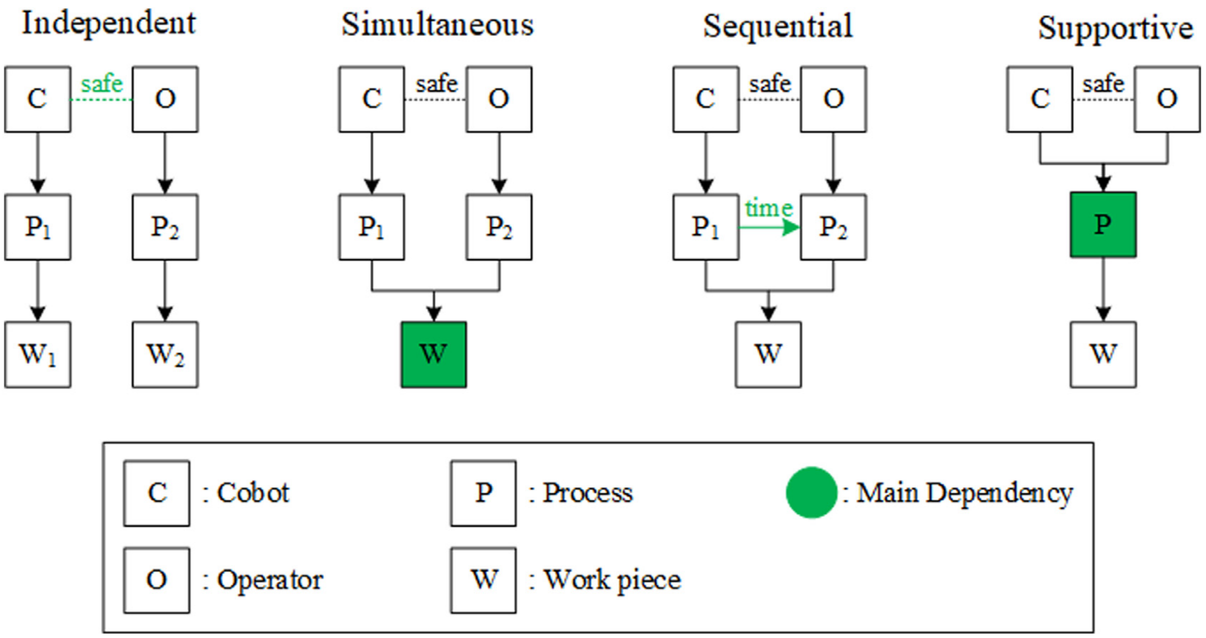
Also, in the professional working environment, Self Determination Theory has been applied and tested (Gagné & Deci, 2005). Not surprisingly, the degree of autonomous job motivation is positively related to an individual's autonomy support in the working environment (Gagné and Deci, 2005). In addition, the authors indicate autonomous motivation to contribute to an individual's well-being, job satisfaction, and performance. In support, Humphrey et al. (2007) showed perceived job autonomy to have a positive relationship with job performance and job satisfaction in their meta-analysis. According to Dysvik and Kuvaas (2011), it is moderated by intrinsic motivation.

Cobots have become an active element in the professional working environment, as illustrated. In the perspective of motivation, it is necessary to distinguish between a cobot and a robot first. Multiple authors (Faccio et al., 2019; Kolbeinsson et al., 2019; Matheson et al., 2019) described several differences, of which the most significant are presented here. First, the kind of application differs. Cobots are robots aimed for collaboration and so the supporting role in the operator's perspective instead of replacing the operator in sake for autonomation like a robot. Second, the work during the collaboration is intended to be executed co-located safely and simultaneously instead of isolated with a fenced robot. Third, since the cobot and operators functioning is in a shared space, the actions of the cobot are purposefully designed to ensure safe production. Fourth, the cobot is lightweight and agile, while most industrial robots are the opposite.

In terms of the collaboration itself, multiple authors have proposed a taxonomy of the type/degree of collaboration between human and robot (El Zaatari et al., 2019; Kolbeinsson et al., 2019; Matheson et al., 2019). For the current study, the classification by El Zaatari et al. (2019) will be used due to the substantial presence in literature. In addition, the authors categorized the collaboration based on the aspects of dependency and task intersection between operator and cobot. These aspects overlap with the intended collaboration by the authors of this study. To continue, the collaboration between human and robot can be classified as 'independent,' 'simultaneous,' 'sequential,' and 'supportive,' of which the classifications are described in an increasingly more collaborative manner (see Figure 1)(El Zaatari et al., 2019). The dependency and interaction between humans and robots are the highest in the 'supportive 'collaboration situation because of a shared process and workpiece. The action of both agents is fully dependent on each other hence the highest degree of collaboration. In comparison, the reason for collaboration in the 'independent' category is solely the safe co-presence of humans and robots while both have a different and separated workpiece and process.

Figure 1

Degrees of collaboration in industrial scenarios (El Zaatari et al., 2019)



Note. Figure 1 visualizes the different categories of collaboration between operator and cobot based on the increasing degree of dependency from left to right. The arrows indicate the direction of responsibility. Marked in green are the elements of dependency in the collaboration for each category. The most basic form of dependency is presented for the 'independent' category in which the operator and cobot only share the same workspace. 'Safe' is indicated as a dependent factor since both agents have to function safely facilitated by the cobot's intrinsic safety features. The 'supportive' collaboration represents the highest degree of dependency. In short, neither the cobot nor the operator can perform without the other, hence the process as a dependent factor.

In collaboration, the cobot is part of a social-technical system shaping the working environment. Furthermore, a cobot can be seen as an autonomously acting agent with attributed autonomy (Zafari & Koeszegi, 2018). Robot (or cobot) autonomy can be defined as the robot's capability to independently perform task-specific goals without external control (Beer et al., 2014). With respect to socio-technical systems like an assembly with integrated cobots, Zafari and Koeszegi (2019) extend this definition by translating it to machine agency, which is the attributed capacity of a robot to execute its goal-directed task autonomously. Alternatively, so to say, machine agency is the extent of perceived machine (cobot) autonomy (Rose & Truex, 2000). More specifically, Rose and Truex (2000) explain that the more agency is attributed, the more the machine is perceived as autonomous.

So, in such social-technical systems, people are tended to attribute (machine) agency to the cobot. The most likely reason for this is people's general tendency to anthropomorphize (Rose & Truex, 2000; Young et al., 2011; Zafari & Koeszegi, 2018). Rose and Truex (2000) indicate that the attributed 'human' agency or autonomy originating based on few human characteristics like independence, volition, and decision making. Interestingly, these characters are very similar to the characters in the description of autonomy by Deci and Ryan (2000) in the Self-Determination Theory. Namely, according to them, an individual act with autonomy when they feel volition (power of choosing) and the experience of choice. An example of the anthropomorphizing of the cobot can be found in a study by Furlough et al. (2019). The authors found humans to blame autonomous robots to almost a similar degree as humans.

In comparison, the attribution of blame to nonautonomous robots was lower than for autonomous robots and barely differed from environmental factors for the error. The results do have to be interpreted with caution since they used scenarios to examine the blame attribution. Another example is that Nass et al. (1996) observed in their study that people who were told to be interdependent with a computer perceived that very computer as part of a team. Moreover, when a person is in a team with a computer, similar behaviors and attitudes were found in a human-human team. That is, a person, for instance, comforted more to the output of the computer, was more open to the computer's influence, and perceived themselves alike. From a general perspective, this is in line with the Media Equation Theory by Reeves and Nass (1996), describing and supporting individuals' general tendency to treat and react to media like real people.

Still, simultaneously anthropomorphizing robots can have a negative impact on the operator. Factors like well-being in terms of stress and perceived control can be impacted when the comparison is made between collaborating with an autonomous (versus nonautonomous) robot.

Although the small amount of research, some insights have been found. For instance, a study by Pollak et al. (2020) investigated the effect of such comparison with a cobot on the operator's stress. They measured the secondary stress appraisal - an evaluative process influenced by an individual's perceived control over their options and resources for coping with stressors-and heart rate as the physiological stress measure. The study involved collaboration in a pill sorting assignment where the manual/nonautonomous robot had to be activated by touching the robot, whereas the autonomous cobot functioned without incentive. The results show that the secondary stress appraisal for the manual collaboration was higher in comparison to the autonomous collaboration. The operator's perceived control to cope with the situation was higher when collaborating with a manual cobot than the autonomous cobot. Along with that, the autonomous cobot showed to induce stress more strongly based on the heart rate. Consequently, the authors argue for the importance of control over the cobot since the autonomous behavior of cobots happens to have a limiting impact on the perception of control and caused stress. Another study performed by Zafari and Koeszegi (2020) contributes to that viewpoint through video assessments presenting a collaboration with either a high agency cobot or a low agency cobot. They show a negative relation between the degree of attribute cobot agency and perception of control in a collaborative assembly context. Furthermore, the high cobot agency simultaneously affects the attitude toward robots negatively, arguably impacting job satisfaction.

Turning back to the essence of autonomy as a psychological need, research has found that workers can express a desire for autonomy in collaboration with a robot. For instance, Tausch and Kluge (2020) show in their model of task allocation process in human-robot interaction that perceived autonomy for the worker is essential for executive quality and satisfaction. Tausch and Kluge (2020) show in a scenario study that workers perceive more autonomy and task identity when the task allocation has been done by themselves compared to a robot or management. In support, Meissner and colleagues (2020) present similar concerns amongst workers specifically for human-robot collaboration in assembly. Namely, when the cobot is taking control, workers experienced the feeling of inferiority to the cobot. In addition, workers indicated the desire to have at least an option for control and decision making in the collaboration and prevent complete dependency on the cobot. In other words, a strong preference for control and autonomy is present among assembly workers.

Shared autonomy in human-robot interaction addresses the 'how' of the fusion between autonomous agents like cobots and humans (Schilling et al., 2019). The idea of shared autonomy is to combine the agents' autonomy leading towards a valuable shared workspace from a human perspective (Schilling et al., 2016). That is, the system can act with autonomy to a certain extent, supporting the human in their task by taking over detailed work. Transparency is an important characteristic of shared autonomy (Alonso & Puente, 2018). In short, transparency in this context can be seen as the ability of a system to anticipate, verify and act on the tasks, goals, and members within (Alonso & Puente, 2018). They explain in their review that an increase in transparency within human-robot interaction contributes to performance and trust in the system and decreases human errors. Bruemmer et al. (2005) presents empirically obtained results supporting that argumentation. They explain that collaborative control or sharing control in a navigation task, where a robot functions as a peer, can increase aspects like performance and decrease errors. Noteworthy is the necessity for the human's ability to adapt in the human-robot team to obtain the most effective trade-off between performance and trust, perceived in a shared table clearing task (Nikolaidis et al., 2017). In addition, Gopinath et al. (2017) indicate to be aware of the preference amongst some to retain more control despite the possibility of improved performance when giving more autonomy to the robot.

Despite the promising perspective in collaboration when autonomy is shared, to our knowledge, no earlier research has empirically investigated the human perception of autonomy when collaborating with an autonomous agent. That is, how an increase of cobot autonomy results in the perceived autonomy of the operator. Consequently, this impacts factors like job satisfaction and well-being. Therefore, the current study has investigated the perceived task autonomy of an operator during an assembly in collaboration with a robot of different levels of autonomous functioning. Additional factors like job enjoyment, perceived control, and physiological stress will be investigated in relation to the perceived autonomy.

The research question to be answered is: **What is the impact of a cobot's autonomy level (low to high levels of autonomy) in assembly on the perceived task autonomy of an operator?** Task autonomy is defined in this study as the perceived autonomy of the operator during the entire assembly. The levels of autonomy are based on the degree of autonomous execution by the cobot. A high level of autonomy is defined for a fully autonomous operating cobot initiating and executing its part entirely independently. A low level of autonomy is defined for a cobot that has to be activated and only executes the pre-set steps for task fulfillment. As the cobot becomes more autonomous, the authors argue that the operator will attribute more autonomy to the cobot. And consequently, the operator will attribute less autonomy to himself. An operator will be asked to assemble a dummy product in the experiments while collaborating with a cobot. The functioning of the cobot will be manipulated to differentiate between degrees of autonomous execution. The experience of the operator will be measure after each scenario.

Based on the described literature and argumentation, the authors argue that in a collaborative assembly task with a cobot, the autonomy level of the cobot can diminish the perceived task autonomy of the operator.

H1: Operators will experience increased loss of perceived task autonomy when collaborating with a cobot being more autonomous.

Along with that, we argue that the loss of perceived task autonomy is a crucial determinant of the reduction in job satisfaction and perceived control. In other words, a reduction of control due to an increase in cobot autonomy will decrease the perceived autonomy of the operator and thereby increase stress and reduce job satisfaction.

H2: Increasing the loss of perceived control will result in a higher level of physiological arousal and lower task enjoyment.

2 Method

2.1 Participants

This study contained 26 participants. The average age was 27.7 (SD = 9.7), with a range of 19 to 66 years old. Seventeen subjects indicated male (65.4%), and nine were female (34.6%). Furthermore, three of the participants finished high school with the highest education (11.5%). Three finished a two-year college degree (11.5%), 12 a three to a four-year college degree (46.2%), seven a master degree (26.9%), and one an educational doctoral degree (3.9%).

The sample for this experiment consisted of employees of two companies (Tegema and Mentech) and acquaintances of the experimenter, everyone located in The Netherlands. Every individual in the final sample was selected because of their lack of knowledge about the study itself in every aspect. Furthermore, the participant had to be 18 years or older.

The sample size was based on an estimation of the potential availability of 25 participants. Using a sensitivity analysis in G*power (Faul, Erdfelder, Buchner & Lang, 2009), this sample size of N = 25 will result in an approximate (medium) effect size of 0.41. This is based on a 90% power, one group, five conditions considering a within-subject design with an alpha of 5%. An availability of participants strategy was used as no similar study was found to serve as a reference allowing a sensitivity test's performance. The final sample size is N=26.

2.2 Experimental Design

This study used a 2x2 + 1 (control condition) within-subject design consisting of five conditions presented in randomized order to each participant. The task of the participant was to assemble a photonic dummy product with a robot. In the execution process, the robot performed one assembly step and, in this way, collaborated with the operator. The robot's behavior varied in four conditions. Each of these conditions represented a different degree of autonomous behavior by the cobot. The fifth, the control condition, is an assembly without the cobot's assistance.

Between the conditions, the degree of autonomy of the cobot is varied. In practical terms, this will be done by manipulating two aspects. The first manipulation is the presence of a button, called 'Button'. The operator can activate the cobot by pressing it and therefore perceive the cobot as less autonomous. Alternatively, the cobot will self-activate without the operator's incentive in which the button option is withdrawn, increasing the autonomous functioning of the cobot. The 'button' control is included to create a direct implementation for perceived control. The second manipulation is called the 'Delay'. This means that the cobot will either hand over the assembled components directly and therefore have no delay. Alternatively, the cobot 'decides' himself when to hand it over by temporarily waiting (in varying lengths), causing a delay for the assembly worker. Besides that, this second manipulation of control is created to have an indirect implementation in which perceived control is retracted. That is, the worker's choice of continuation during the assembly has been retracted due to the autonomous behavior of the cobot. The combination of both is aimed to give the cobot varying autonomy based on varying levels of autonomous execution. In order to evaluate the effect of autonomous functioning by a cobot in an assembly collaboration, perceived autonomy by the operator has been measured as a primary interest. Furthermore, the perceived control over the cobot, the task enjoyment, and stress levels will be measured as additional variables.

Consequently, four conditions are tested, each shaping a different level of cobot autonomy. The condition including only a button and no delay represents the lowest degree of autonomous cobot behavior named 'Low cobot autonomy'. Noteworthy, this condition is still indicated as low since the execution of the task by the cobot is automated. The condition with no button and delay represents the cobot with the most autonomous functioning named 'High cobot autonomy'. The other two conditions will be named 'Semi cobot autonomy'. More specifically, one condition includes a button and delay named 'Semi – BD', whereas the other does not include a button and functions without delay named 'Semi – nBD'. These two conditions are argued to be between the low and high conditions. However, no clear argumentation was found for an order within the semi-conditions. Along with that, no direct argumentation was found for the effect of both manipulations. Table 1 includes the mapping of each condition subjected to the manipulations.

Table 1

Mapping of conditions in respect to manipulations Button and Delay

Button	Delay	
	Yes	no
Yes	Semi - BD	Low
no	High	Semi - nBD

2.3 Materials

The test environment for this study was located within a lab at the system integrator Tegema where Tegema provided an assembly set-up. The set-up was shaped out of a Pick to Light system, a cobot, assembly product, and tools for assembly. The Pick to Light system provides a means for the assembly process by indicating (flashing LED) which component needed to be picked in the sequential order of assembly (Figure 2). The system used movement sensors to register if the participant had picked the component, followed by relocating the indicating bin light.

Figure 2

Assembly set-up for the experiment: The Pick to Light (left), plus cobot stand (right)

The cobot, the ABB Collaborative YuMi type IRB 14050 Single-arm (Figure 3), was placed on its assembly table, moving at a speed of 500mm/s.

Figure 3

***The ABB Collaborative YuMi type IRB 14050 Single-arm*(*ABB Collaborative YuMi Type IRB 14050 Single-Arm*, n.d.)**

It was positioned to the operator's right and provided a fiber-spring combination for assembly (Figure 4). The cobot picked up an fiber, placed it in a holder on which a spring was placed. As can be seen in Figure 5, the component trays for the fiber and spring were positioned behind the cobot observed from the perspective of the participant. The holder for assembly was placed aside of the cobot on the right, from which the cobot would pick up the assembled parts to be placed on the side close to the participant in the predetermined slots. Figure 6 presents a profile of the assembly product in which the position of the fiber-spring combination is visible. When the combination was assembled, the cobot was transported and placed in the predetermined slots for the operator to take (Figure 6). The contribution of the cobot to the assembly is positioned between steps three and four and so halfway in the process (See appendix Assembly Process). Furthermore, the operator is provided with an electric screwdriver for the assembly, a tool to hold the product during assembly (See appendix Assembly Process) along with an automatic screw dispenser.

Figure 4

Orientation Worker and Cobot

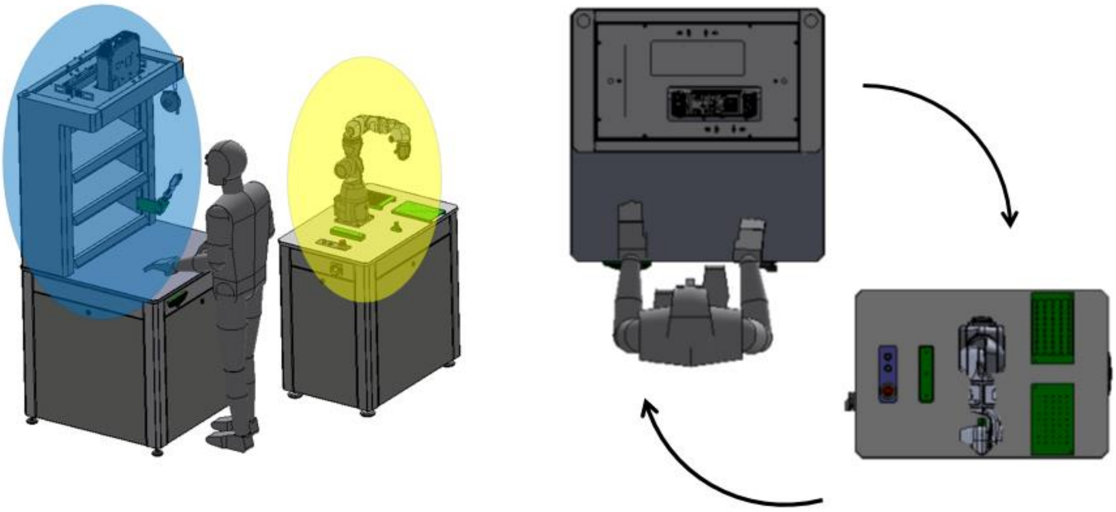


Figure 5

Workstation cobot

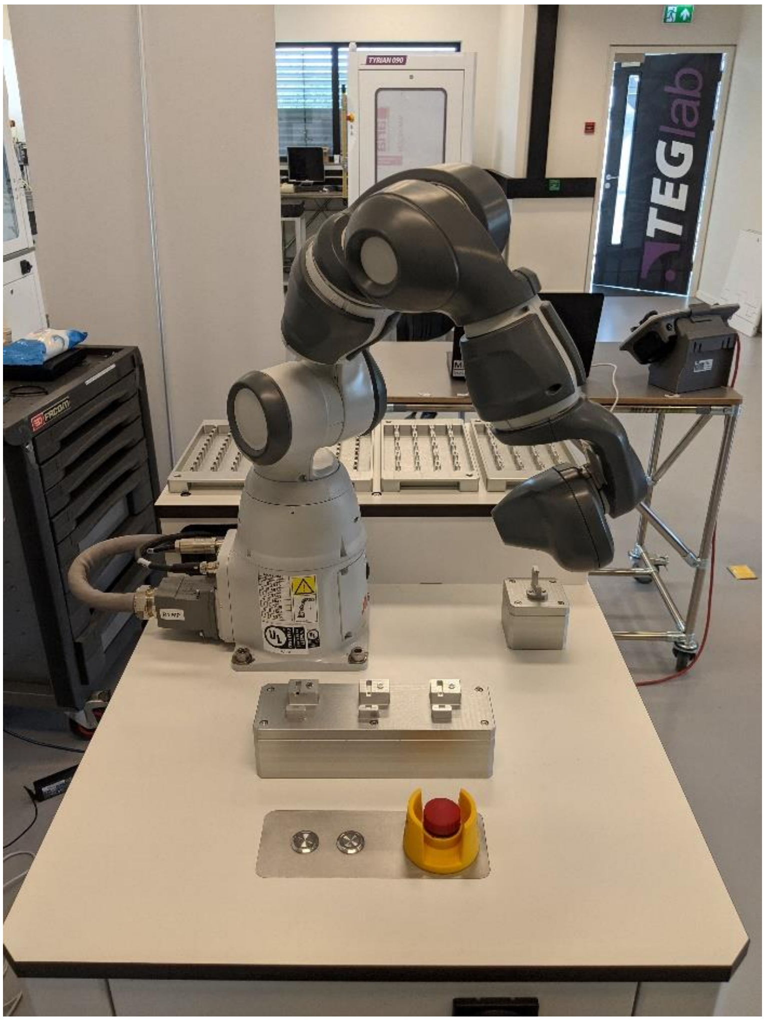


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Figure 6

Assembly product

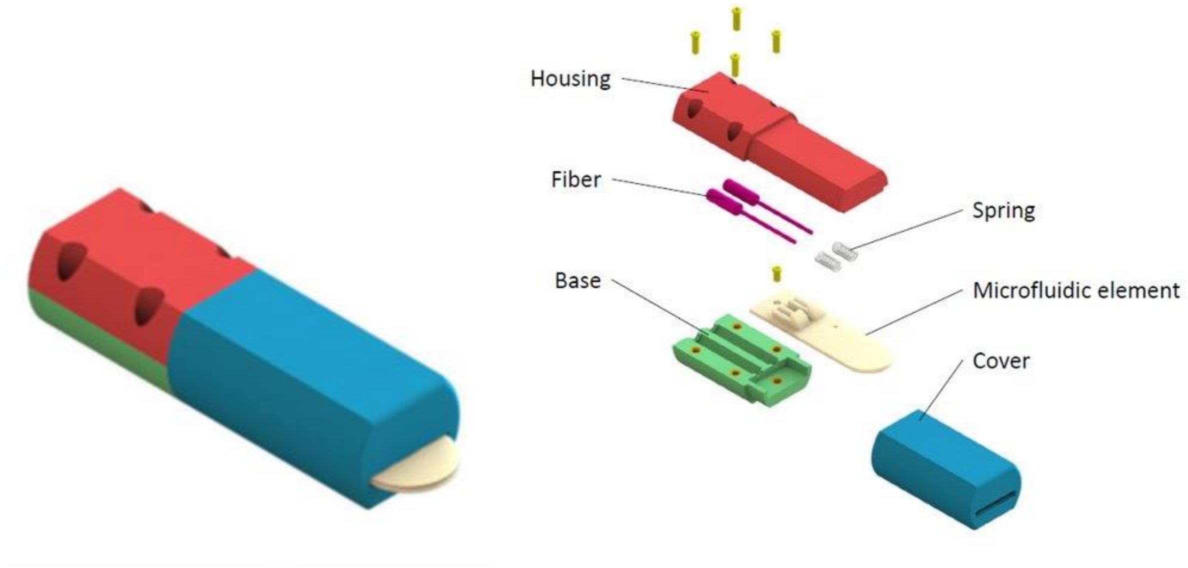
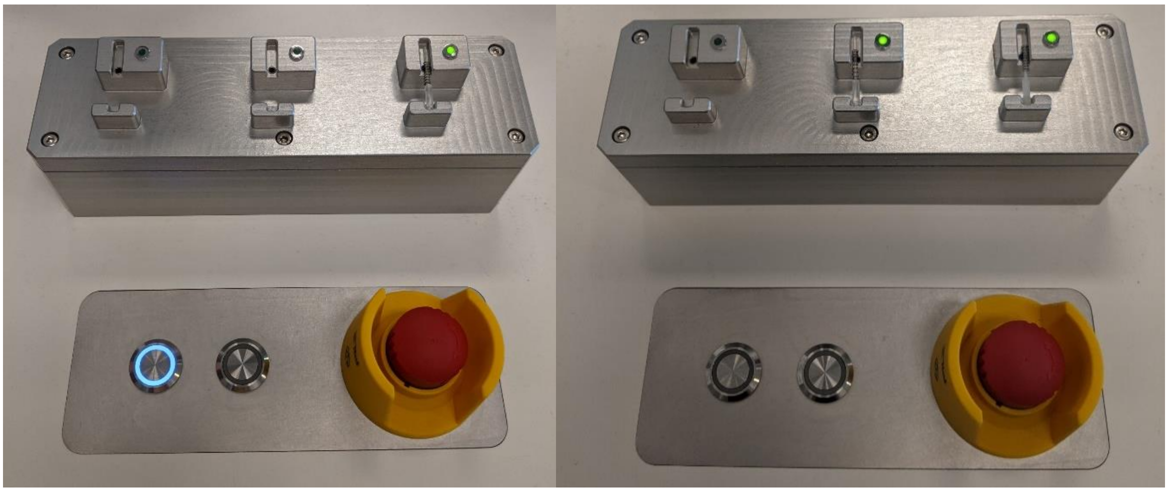


Figure 7

Activation button (left: on, right: off) and holders Fiber-Spring combination (top)



To answer the hypotheses, perceived task autonomy, perceived control, task enjoyment, and stress level have been measured. The independent variable is the degree of autonomous execution by the cobot. Since the close relation between perceived control and autonomy, the perceived control will function as a manipulation check. When applicable, the general attitude towards robots and the operator's desirability of control as additional measures will be used. The survey providing the means of measurement has been presented and obtained on a laptop with that as the sole purpose. LimeSurvey has been used as a tool for survey creation and presentation.

2.4 Measurements

To measure *physiological stress*, the experimenter measured psychophysiological variables continuously during the experiment using the HUME developed by Mentech. The HUME is an emotion (stress) recognition platform that translates physiological output with a model into a stress probability (Mentech Innovation B.V., n.d.). The physiological response is obtained with a combination of the Sentisock, a skin conductivity measuring sock, and a chest strap sensor measuring the heartbeat and inter-beat interval. The model providing the stress probability is developed by Mentech. This arousal model uses a neural network based on behavior models to generate the output. For this study, the average over all the layers within the model is taken for each second input, then combined and averaged to provide a general stress probability per participant per condition. Most of the model's 'outliers' are indicators of high arousal. Actual outliers were identified and excluded before being processed in the stress model.

Along with that, the raw physiological data has been filtered and cleaned up due to potential turbulence during measurement, causing the noise. The model output is a stress probability ranging between 0 and 1 used to verify the hypotheses. The model itself is developed on high arousal VR content (scaring) before implementation in this study. Still, the ratio between the conditions remains constant and therefore deemed usable for this study. Moreover, the original application of the HUME within care houses has proved to be effective for emotion detection (stress probability) even when low and slowly fluctuating physiological stress levels were measured. It is, therefore this study has provided a means to apply this tool in a new domain.

Along with that, self-report surveys have been used at the end of each condition. Perceived task autonomy, perceived control over the cobot, and task enjoyment were measured in the idea of the following instruction "In your response to these statements, consider your activity as an operator in your last finished assembly.". The order of items was consistent between each condition to ensure the focus would be on the difference between assembly activity and collaboration instead of distracting the participant with a randomized order. A final questionnaire was used to measure the desirability of control, attitude towards robots, and demographics (age, gender, and educational level). All the constructs aside from the demographics used a 7-point scale. The survey can be found in Appendix I.

The experimenter used the seven 'Need for autonomy' items from the Work-related Basic Need Satisfaction scale by Van den Broeck et al. (2010) to measure *perceived task autonomy*. They have used the psychological needs derived from the Self-determination theory as a basis for scale development, and therefore the job autonomy-related questions were used. To prevent confusion, some of the questions have been altered to reflect the task at hand instead of a job in general. Examples of adjusted questions are "In my job, I feel forced to do things I do not want to do" altered to "In this activity, I felt forced to do things I did not want to do." and "I feel like I can be myself at my job" adjusted to "I felt like I could be myself during this activity." Participants were asked to which extent the statement applied to them, and they had to respond on a seven-point Likert scale ranging from 1 (Totally disagree) to 7 (Totally agree). Furthermore, items that were reversed were transformed before testing for internal consistency. After closer inspection of the factor analysis, question two was removed (i.e., 'During this activity, I often felt like I had to follow other people's commands') to ensure an alpha value larger than .7 over the perceived task autonomy scale in every condition. In effect, by averaging these six items, we were able to calculate a reliable (Cronbach's alpha = .88) measure for perceived task autonomy.

To measure *perceived control*, we used a combination of items. Four questions in total sourcing from two authors were used to examine the direct perceived control. Two questions by Hinds (1998) were used, who developed a scale for perceived control in Human-Computer interaction (e.g., "I felt I was in control"). Furthermore, two questions by Ninomiya et al. (2015) from their Multi-dimensional Robot Attitude Scale in the dimension 'Control' were used (e.g., "I think a robot could recognize me and respond to me."). Ninomiya et al. (2015) has created the scale in perspective of domestic robots and created three questions in total for the control dimension. The question "I want to tame a robot according to my preferences." has been excluded by the experimenter since it was inapplicable within the scope of the cobot interaction for this study. Namely, the operator was not provided with a choice for personalized preference and could therefore not tame the cobot by default. All questions used a seven-point Likert scale ranging from 1 (Not at all) to 7 (Very much) to respond on whether the statements applied to the operator considering the assembly task and collaboration with the cobot. More specifically, the internal consistency of our measure of perceived control was tested for each condition with all four questions included resulted in a varying value for the perceived control scale with the majority of the conditions scoring well below the desired value of Cronbach's alpha ($\alpha = .7$). After closer inspection, both questions included from the Multi-dimensional Robot Attitude

Scale (Ninomiya et al., 2015) did strongly deviate. Probably because of the different domain of aimed application. Therefore, these questions were excluded effectively using the two questions remaining from Hinds (1998). For each condition, these questions presented a respectable internal consistency with a Cronbach's alpha > .7. In effect, by averaging these two items over all conditions, we were able to calculate a reliable (α = .84) measure for perceived control.

To measure *task enjoyment*, we used items from the Intrinsic Motivation Inventory (Ryan, 1982). This inventory is used to assess the motivation for specific tasks in which several domains (e.g., effort, value/usefulness) are included. The creation of the items is based on the Self-Determination Theory of motivation, and it is therefore used in this study. To be more precise, the "interest/enjoyment" subscale has been used to measure the assembly Task enjoyment. Example questions are "I enjoyed doing this activity very much" and "I would describe this activity as very interesting.". The participants were asked if the statements were true to them and were asked to respond on a seven-point Likert scale ranging from 1 (Not true at all) to 7 (Very true). The internal consistency was tested for each condition presenting a Cronbach's alpha > .7. In effect, by averaging these items over all conditions, we were able to calculate a reliable (α = .97) measure for task enjoyment.

As the first extra general measure, a participant's general *attitude towards robots* has been measured with the Robotic Social Attributes Scale (RoSAS) (Carpinella et al., 2017). The scale measures an individual's social perception of robots. The participant had to respond on a seven-point Likert scale ranging from 1 (Definitely not associated) to 7 (Definitely associated), indicating the degree of association with a specific term. For this study, the general category of robots was asked to be considered while responding to the terms (e.g., Happy or Capable). Interestingly, during the tests for internal consistency of each subcategory, one item within the category impacted the Cronbach's alpha value to become lower than .7. Arguably the following terms could be excluded due to the negative impact: 'Organic' in the warmth subcategory, 'Aggressive' in the discomfort subcategory, and 'Knowledgeable' in the competence subcategory. A case could be made for exclusion since the creation and validation of the RoSAS scale has been based on humanoid robots. In this study, the scale was tested for the broader domain 'category of robot'. Each of the terms can logically be attributed to robots' social and human perception, which can be questioned when considering the collaboration robot in this study; let stand the category of robots in general. Nevertheless, since RoSAS is a validated scale and each of the subcategories show an α = .7 when rounded off to one decimal, no items were excluded. The presentation of the items has been randomized likewise to the procedure by Carpinella et al. (2017).

As a second extra general measure, the *desirability of control* has been measured. In a broad sense, it covers the extent to which individuals want control (Burger, 1992), for which the Desirability of Control (DoC) scale developed by Burger & Cooper (1979) has been used. Precisely, the DoC scale measures the extent to which individual desires to control the events in one's life. It has been included to place the perceived control in perspective. The participants were asked whether each of the statements applied to them and responded using a seven-point Likert scale ranging from 1 (Not at all) to 7 (Very much). In effect, by averaging the DOC items, we were able to calculate a reliable (α = .79) measure for Desirability of Control.

2.5 Procedure

Participants were invited by spreading invitations within both companies, Mentech and Tegema, and amongst acquaintances of the experimenter with no predetermined preferences. The search for participants continued till a minimum sample of 25 was achieved. Each of the participants was sent an official invite, including all details after the verbal confirmation. No individual has neglected to participate after verbal agreement.

Every experiment started with welcoming the participant and asking them to begin with the set-up. They were instructed to read the informed consent, fill in a COVID-19 register, and put on the HUME instruments when in agreement with the informed consent. In the next step, the participant was informed about the purpose of this study. They were told that this experiment would improve the understanding of 'smart' assembly, specifically, the effectiveness of cobot collaboration in an assembly task. This, without revealing any information about the actual aim of the study. Right after, the participant was instructed to take place behind the Pick to Light system.

Before the actual assembly instructions were provided, the operator was asked to activate the cobot by pressing the button to show the cobot's capabilities. When the cobot was finished, the attention was directed at the Pick to Light system itself. Information was provided about the functionality of the Pick to Light, the assembly itself, and tools. The first three products were intended as a practice round to ensure the operator understood what and how the product should be assembled. During this first round, the operator had to assemble the product without the cobot. Furthermore, each product had to be assembled before the next throughout the experiment.

When the practice round was finished, the participant was told the actual test would begin. They were told that each round consisted out of three products which they had to assemble with or without a cobot. After each session of three, they were asked to fill in a survey about that assembly session at a table placed away from the set-up to come back to continue with the next session. Furthermore, the experimenter instructed them to focus on the assembly itself and the collaboration with the cobot. Before the start of every session, the experimenter instructed the operator when they could begin and whether they should activate the cobot or it would do it himself.

After five sessions (all conditions), the operator was instructed to fill in the last session survey and a final additional survey consistent with the Desirability of Control Scale, the RoSAS scale, and demographics. The moment the participant was finished with answering, they were asked to take off the HUME instruments and any remarks or questions. After thanking participants for participation, they were debriefed. The experiment took approximately 80 minutes in total for each participant.

2.6 Statistical analysis

The statistical analysis has been done by means of StataIC 16 (64bit). A repeated-measures ANOVA was used to test the hypothesis and answer the research question. Prior to the analysis, the data was processed and examined on errors and outliers. Each of the adjustments is discussed per variable.

Perceived task autonomy

Before executing the repeated measures ANOVA, the perceived task autonomy for each condition was tested for outliers, followed by testing the assumptions of sphericity and normality. The data has been tested for outliers based on graphical representations, the absolute z-scores of standardized observations, and an observation's value relative to the variable's interquartile range (IQR). Observations being $|z| > 4$ or have a value above the 1.5*IQR limit or below the -1.5*IQR limit were considered outliers. Only condition one showed to have an outlier present outside the '-1.5* IQR' value. Taking that into account, condition one alongside the other conditions was tested for normality based on the variable's skewness, kurtosis, and outcome of the Shapiro-Wilk test. For conditions two to four, no arguments were found to question normality. Condition one was not significant for the joint test of skewness and kurtosis ($p = .08$) and test of skewness ($p = .05$). The Shapiro-Wilk test showed to be non-significant ($p = .17$) but with a questionable W-value ($W = .94$) taken $W = .97$ as threshold. Normality was tested again with the outlier excluded effectively, resulting in an improved non-significant Shapiro-Wilk test ($W = 0.97$, $p = 0.70$) and a non-significant test in skewness and kurtosis joint ($p = .28$). Therefore the outlier was removed from further analysis. Condition five showed to have some problems with normality. A significant p-value was observed for skewness ($p = .02$) effectively impacting the joint p-value with kurtosis to be $p = .05$. The Shapiro-Wilk test showed a significant p-value ($p = .01$) as well. Nevertheless, no measures were taken to adjust for normality. First, the skewness towards higher perceived task autonomy in condition five is not unexpected, and the Shapiro-Wilk test is susceptible to lower sample sizes. Second, the non-parametric Friedman test showed no different outcome ($p < .001$) than the parametric test.

The sphericity assumption was examined based on the epsilon values of the conservative F-tests considered: 1) Huynh-Feldt ($\varepsilon = 0.85$), 2) Greenhouse-Geisser ($\varepsilon = 0.74$) and 3) Box’s conservative ($\varepsilon = 0.25$). All of the conservative F-test remained significant ($p < .001$), similar to the parametric test. Along with that, a MANOVA has been conducted as an alternative method resulting in $F(4,124) = 18.59$ and $p < .001$. Since none of the alternatives presents a different result than the repeated-measures ANOVA, sphericity violation is deemed not problematic.

Perceived control

The perceived control variable has likewise been examined for outliers per condition before testing for the assumptions of sphericity and normality. The data has been tested for outliers based on graphical representations, the absolute z-scores of standardized observations, and an observation's value relative to the variable's interquartile range (IQR). Observations being $|z| > 4$ or have a value above the 1.5*IQR limit or below the -1.5*IQR limit were considered outliers. Only Condition four and five did not have any outliers. Conditions one, two, and three had one, two, and three outliers in the named order of conditions. Each of the outliers was present outside the -1,5*IQR value.

The assumption of normality is consequently tested with and without outliers. Normality has been tested using tests for skewness and kurtosis along with the Shapiro-Wilk test. After removing the outliers from Condition one, the significant joint p-value (p = .02) of skewness and kurtosis improved to a non-significant p-value (p = .43). Furthermore, the Shapiro-Wilk test improved likewise from the values W = .92, p = .04 into W = .097, p = 0.72. The removal of the two outliers in condition two had a similar impact. The test for skewness and kurtosis was not significant, but the Shapiro-Wil was not significant (W = .0.92, p = .06). Removing outliers improved the Shapiro-Wilk test (W = .96, p = .28), ensuring no normality violation. The same goes for the removal of three outliers in condition 3. With the outliers included, the joint test for skewness and kurtosis was barely not significant (p = .06) along with a significant Shapiro-Wilk test (W = .90, p = .02). Removing the outliers resulted in not violating normality as the joint test for skewness and kurtosis (p = .36) and Shapiro-Wilk test (W = .98, p = .89) clearly improved. Condition four revealed no arguments for the violation of normality. Incomparable fashion to Condition five for perceived task autonomy, C5 perceived control showed some normality problems. A significant p-value was observed for skewness (p = .05). Also, the Shapiro-Wilk test showed a significant p-value (p < .001) as well. Nevertheless, no measures were taken to adjust for normality because the non-parametric Friedman test showed no different outcome (p < .001) than the parametric test.

The assumption of sphericity was tested based on the epsilon values of the conservative F-tests considered: 1) Huynh-Feldt (ε = .65), 2) Greenhouse-Geisser (ε = .58) and 3) Box’s conservative (ε = .25). Arguably a correction to the degrees of freedom would be appropriate. Nevertheless, according to O'Brien and Kaiser (1985), it is recommended to select the repeated measures in case N > k+10 (k is the number of factor levels) with a large violation of sphericity (ε < .70) to keep power.

Attitude towards robots

Likewise to other measured variables, each subcategory has been examined for outliers before testing for normality. The data has been tested for outliers based on graphical representations, the absolute z-scores of standardized observations, and an observation's value relative to the variable's interquartile range (IQR). Observations being |z| > 4 or have a value above the 1.5*IQR limit or below the -1.5*IQR limit were considered outliers. Only the subcategory 'competence' showed to have two outliers. Both of the outliers were present outside the -1,5*IQR value.

Normality is consequently tested with and without outliers using tests for skewness and kurtosis along with the Shapiro-Wilk test. After removing the outliers the significant joint *p*-value (p = .0011) of skewness and kurtosis improved to a non-significant *p*-value (p = .34). Furthermore, a similar impact was observed for the Shapiro-Wilk test showing p = .0011 with outliers and p = .67 with outliers excluded. So, normality was accepted after removing the outliers.

3 Results

3.1 Participant flow

For this study, 29 participants have been tested, of which three were contributed during the preliminary test period, followed by 26 for the final study. Each participant has been active in all conditions which have been tested in a randomized order. All participants in the final study have completed the experiment fully, including every measurement aspect, effectively meaning no missing data.

3.2 Statistical and data analysis

Providing support for our first hypothesis, results showed that participants experienced an increase in loss of perceived task autonomy when collaborating with a cobot that acted more autonomous, indicated by the effect of our manipulation of robot autonomy, $F(4, 99) = 28.79$, $p < .001$ and $\eta_p^2 = .54$. More specifically, participants who had interacted with a Low autonomy cobot indicated that they perceived their task autonomy to be higher ($M = 5.53$, $SD = 0.80$, $N = 25$) than participants who had interacted with the Semi – BD autonomy cobot ($M = 4.49$, $SD = 1.29$, $N = 26$), who again perceived more task autonomy than participants who had interacted with the Semi – nBD autonomy cobot ($M = 3.83$, $SD = 1.05$, $N = 26$), than participants who had interacted with the High autonomy cobot ($M = 3.37$, $SD = 1.32$, $N = 26$) (see Figure 8). Participants who had no robot collaboration during assembly experienced a comparable perceived task autonomy as too the participants who interacted with a low autonomy cobot ($M = 5.34$, $SD = 0.93$, $N = 26$). Table 2 shows these means (and SD's) and how they differ from one another. Each of the differences is in line with what was expected for perceived task autonomy. More precisely, no clear distinction has been visible between participants' experiences when collaborating with the 'Semi' autonomy cobots. Along with that, no significant difference was found in the participant's experience when completing an assembly in the control condition and with the 'Low' autonomy cobot. Furthermore, participants have perceived their task autonomy significantly different when collaborating with a robot with 'Low' from the cobot with 'High' autonomy.

Figure 8

Means perceived autonomy, perceived control, and task enjoyment

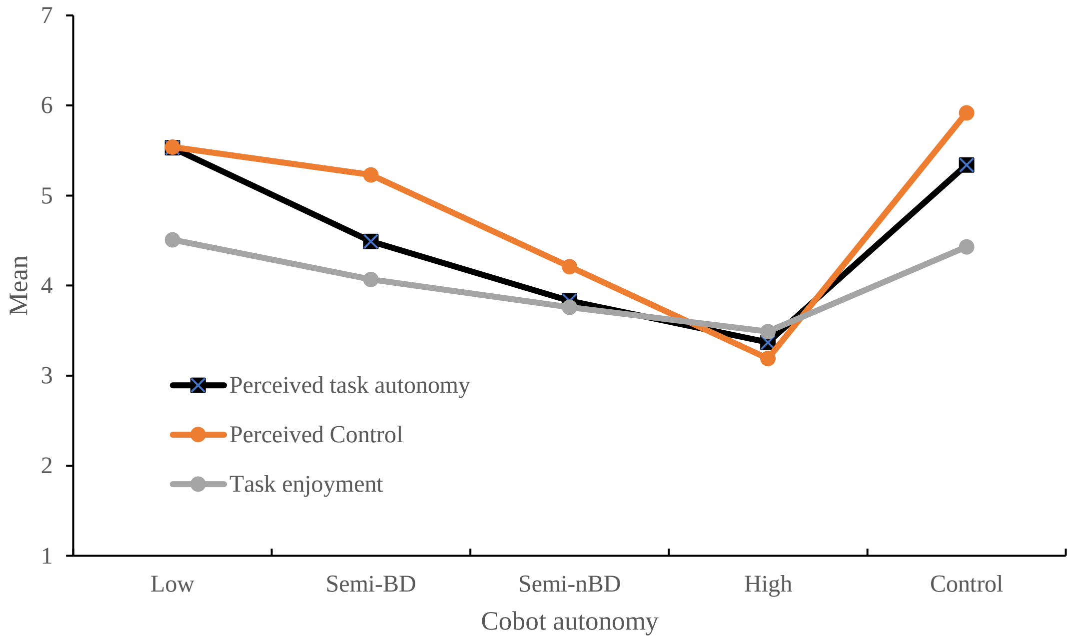


Table 2

***Pairwise comparison conditions over** perceived task autonomy*

Cobot autonomy	Perceived task autonomy	
	M	*SD*
Low $_{b\ c\ d}$	5.53	0.80
Semi – BD $_{a\ d\ e}$	4.49	1.29
Semi-nBD $_{a\ e}$	3.83	1.05
High $_{a\ b\ e}$	3.37	1.32
No cobot $_{b\ c\ d}$	5.34	0.93

Note. Means with different subscripts differ at $p < .05$

$_a$ *Mean different from Low cobot autonomy,* $_b$ *Mean different from Semi - BD cobot autonomy,* $_c$ *Mean different from Semi - nBD cobot autonomy,* $_d$ *Mean different from High cobot autonomy,* $_e$ *Mean different from Control: no cobot*

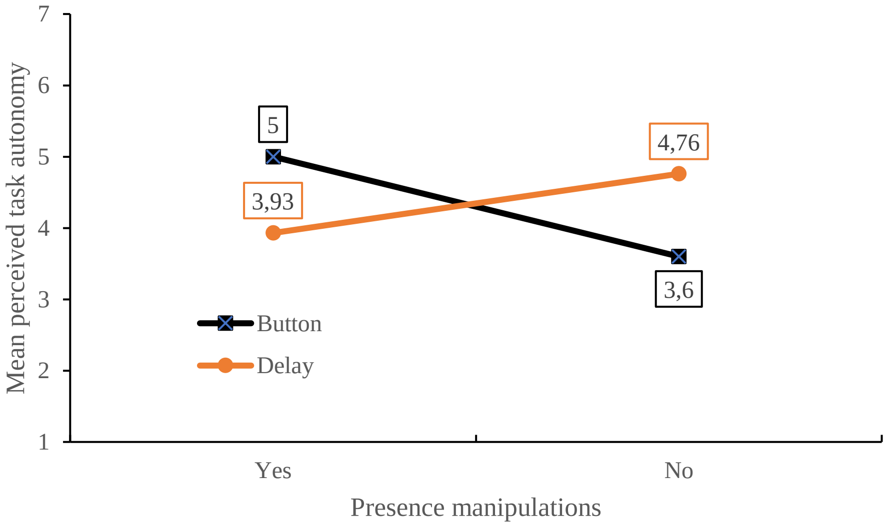
Furthermore, the results provided partial support for our second hypothesis. That is, we tested whether losing perceived control resulted in a higher level of physiological arousal and lowered task enjoyment using Pearson's Correlation Coefficient testing. Results provided no evidence for a correlation between a participant's perceived control and a participant's stress probability $r(121) = -.03$, $p =.76$. Still, results did provide support for our second hypothesis in suggesting that a participant's perceived control was positively correlated with a participant's task enjoyment, $r(121) = .52$, $p < .001$.

3.3 Exploratory analyses

The experimenter also explored the effects of the specific manipulations of cobot autonomy (the availability of a button and the delay of the cobot). Therefore, we submitted the different effects of our manipulations of Button and Delay as independent variables to a 2 x 2 repeated-measures ANOVA with perceived task autonomy as the dependent variable. Results of this analysis presented evidence for two main effects but no interaction (Figure 9). That is, when a participant had interacted with a cobot while a button was present, he or she indicated to experience more task autonomy ($M = 5.00$, $SD = 1.18$) than when a participant had interacted with a cobot while no button was present ($M = 3.60$, $SD = 1.20$), $F(1,24) = 70.67$, $p < .001$ and $\eta_p^2 = .74$. Furthermore, when a participant had interacted with a no delay cobot, he or she indicated to perceive more task autonomy ($M = 4.67$, $SD = 1.26$) than when a participant who had interacted with a delayed cobot ($M = 3.93$, $SD = 1.41$), $F(1,24) = 28.27$, $p < .001$ and $\eta_p^2 = .53$. The interaction between both manipulations was not significant $F(1,24) = 1.57$, $p = .22$ and $\eta_p^2 = .06$.

Figure 9

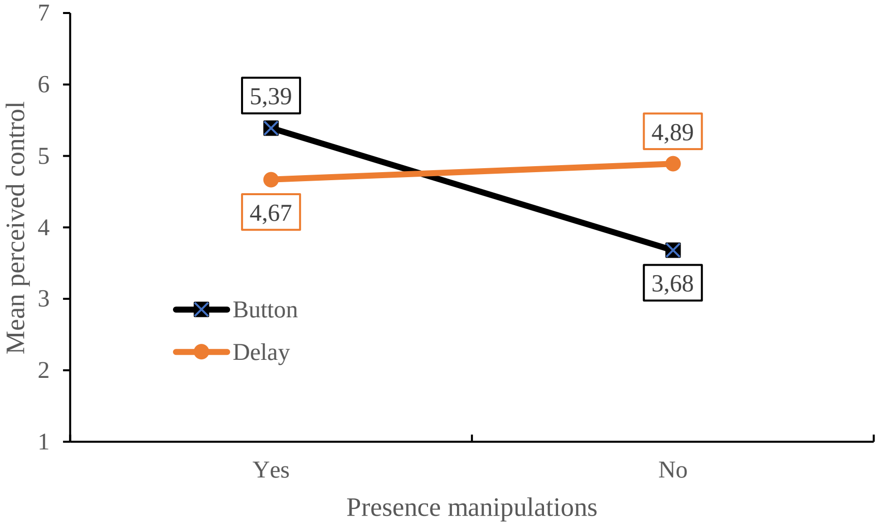
Manipulations on perceived task autonomy



Along with that, we explored the effects of the specific manipulations of cobot autonomy (the availability of a button and the delay of the cobot) for perceived control. Therefore, we submitted the different effects of our manipulations of Button and Delay as independent variables to a 2 x 2 repeated-measures ANOVA with perceived control as the dependent variable. Results of this analysis presented evidence for two main effects and interaction (Figure 10). That is, when a participant had interacted with a cobot while a button was present, he or she indicated to perceived more control (*M* = 5.39 , *SD* = 0.85) than when a participant had interacted with a cobot while no button was present (*M* = 3.68 , *SD* = 1.35), *F*(1,20) = 68.12, $p < .001$ and $\eta_p^2 = .70$. Furthermore, when a participant had interacted with a no delay cobot, he or she indicated to perceive more control (*M* = 4.89 , *SD* = 1.20) than when a participant who had interacted with a delayed cobot (*M* = 4.12, *SD* = 1.54), *F*(1,20) = 5.13, *p* = .0043 and $\eta_p^2 = .30$. The interaction between both manipulations was significant *F*(1,20) = 3.05, *p* =.03 and $\eta_p^2 = .23$. Based on the pairwise comparison, it becomes clear that delay manipulation had no impact when the button was present, showing no significant difference between a delay-button combination and a no delay-button combination (*p =.76).*

Figure 10

Manipulations on perceived control



4 Discussion

This experiment aimed to study the effects of collaboration with a cobot in assembly on the perceived task autonomy, perceived control, task enjoyment, and stress levels for different levels of autonomous function by the cobot. To our knowledge, the present study is the first to investigate these effects in an empirical study that included a real cobot and assembly set-up.

The results showed that participants' perceived task autonomy decreased as the cobot became' more autonomous, yielding support for our first hypothesis. Participants who interacted with a low autonomy cobot perceived more task autonomy than when they interacted with a semi autonomous cobot which was operable with a button (semi-BD). This is still more than participants who interacted with a semi-autonomy cobot who started by itself (semi-nBD), which is more than the perceived task autonomy of participants collaborating with a high autonomy cobot functioning completely autonomous. Interestingly, no clear differentiation was observed between the impact of the least autonomous execution by the cobot – low cobot autonomy: button activation, no delay - in comparison to the control condition in which no cobot was active. This observation suggests that the importance of control over choice in the cobot’s task initiation is an essential element to the perceived task autonomy. This is in line with the observations made by (Meissner et al., 2020), indicating the desire for autonomy and control in collaboration with a cobot in assembly amongst workers. The most probable argumentation for this impact of autonomy shift is due to the degree of collaboration. Namely, the set-up is tuned for the highest degree of dependency between cobot and operator by simultaneously performing, in the same process, while working towards the same assembly product. Therefore, the collaboration can be categorized as 'supportive' (El Zaatari et al., 2019). The interdependency in the cobot-human teamwork likes to have a similar impact on the human collaborator as shown between computers and humans by Nass et al. (1996). That is, the participants seem to be open to the influence of the cobot during collaboration as the cobot is most likely seen as a teammate because of the intended collaboration. Especially in the most autonomous execution, it can be argued that the cobot would be attributed more agency and thus be perceived as more human.

The second point of interest was the overall task enjoyment and stress level of the operator. Regarding these aspects, the results showed that the more the operator decreased in perceived control, the lower the observed task enjoyment. This means partial support for our second hypothesis: Increasing the loss of perceived control will result in a higher level of physiological arousal along with lower tasks enjoyment. That is, the stress levels did not differ between any of the participants for each degree of cobot autonomy. To continue, the decrease of task enjoyment and perceived control is not surprising. Humphrey et al. (2007)indicated a positive relationship between job autonomy and job satisfaction. A decrease in autonomy would suggest a drop in the experience of choice when following the explanation of autonomy by Deci and Ryan (2000). The perceived control would therefore result in a decrease of perceived autonomy, hence the logical relationship. Along with that, Pollak et al. (2020)stated the importance of control in their study, which effectively impacted the experience of stress. To be more precise, the observed results were expected to be different based on the result by Pollak et al. (2020). That is, no clear distinction between the effect of different degrees of cobot autonomy was found for the stress levels within this study. Noteworthy are the possible limitations impacting the measurement, so it does not take away the possible impact on stress.

Furthermore, the exploratory results of this study showed that the manipulations applied were effective to a different extent. The difference between the impact of button or delay on perceived control is noticeable and comparable to perceived task autonomy. The inclusion of a delay to withdraw the perception of control happened to be only significantly effective when no button was offered. Consequently, in the condition that a button provided a means for control over the cobot, the impact of the delay was clearly overshadowed. For perceived task autonomy, the inclusion of delay did have a substantial impact even though the presence of a button. This observation can be argued to be suspected since the delay caused the worker to wait for the cobot and thus was not completely free to decide with full autonomy to proceed as desired.

5 Limitations & future work

Despite the best efforts and novel significant results, some limitations do have to be acknowledged. First, the participant sample might not be a good representative for society. Almost all participants indicated to have obtained a diploma in higher education, and roughly two-thirds of the sample was male. Furthermore, no participant indicated any experience with robot collaboration, especially not in an assembly setting. Future studies are recommended to include an improved representative sample which is advised to be recruited in an ecologically valid environment like an industrial assembly setting.

Second, the set-up for the experiment might have introduced some unpredicted external factors impacting the results. In the perspective of the Pick to Light system, the mere presence of a fiber bin and spring bin could have influenced the perception of complete dependency on the cobot. Even though the strict instructions were not to, the participant could always 'solve' an error by the cobot in times of collaboration. The choice to include these bins in the set-up was to minimize the intervention during the entire process to secure the most stable testing environment possible. Along with that, the fibers and springs were more fragile to repeated usage than expected. On some occasions, the cobot executed its task unsuccessfully because the fiber would either break while the spring was placed or the cobot would stop because the edge of the spring would bump onto a slightly crooked fiber. As a solution, the experimenter immediately directed the attention from the cobot to the fact that the fibers were 3D printed while ensuring the continuation of the cobot execution correctly. A recommendation is the usage of a between-participant design in which conditions can be tested where the dependency between humans and cobot can be secured. Furthermore, an alternative to the assembly product is advised to prevent potential disturbance by the product itself.

Third, the manipulations during the experiment might have caused an altered interpretation than intended. The inclusion of the delay could have been perceived as a malfunction instead of the aimed attribution of autonomy to the cobot because it would have an 'attitude'. This might have been the case, especially for the participants who started with conditions one or two not having a delay. Moreover, this might be the reason why the effect of the delay as manipulation is overshadowed when the button is presented. In that line of thought, one could argue for a too low level of dependency between operator and cobot. Despite the best efforts to ensure a shared process and workpiece, the assembly process can be best termed sequential instead of supportive (El Zaatari et al., 2019). The cobot and operator performed a sequential process when no delay was included, contributing to a single workpiece by different processes. However, when participants collaborated with a cobot that had a delay, the collaboration could be stated as supportive. The operator had to wait for the cobot to hand over its parts, making the operator's process dependent on the cobot due to the collaboration within one process. A potential concern is an influence on perceived autonomy on this 'lower' level of collaboration dependence. Nevertheless, even for this type of close to completely interdependent collaboration, strong effects are observed. A possibility for improvement is a different kind of assembly product. That is, the shared contribution by humans and cobots can be secured when both will simultaneously and together assemble the same workpiece.

That being said, the factor creating the dependency was the time of task execution. The quality of the component combination by the cobot had barely influenced the actual assembly. More specifically. The cobot provided its parts till the operator was sufficed. Simply put, the position of the cobot was like a bin supporting the operator in terms of the assembly itself. The time it took for the cobot to execute its task caused the operator to interact and depend on it. Therefore, it is not completely certain if the participant perceived the loss of control with respect to the cobot or the assembly itself. Still, the experiment was designed in such a way that the operator always had control over every step except the cobot. In addition, the button manipulation clearly showed a more substantial impact on the perceived control, arguably showing the indicated experience by the operator did reflect the interaction with the cobot. In future perspective, technological advancements like gestures or speech can provide better 'controls' within the collaboration for the human. These are recommended to be tested since the current means for control are not directly based on literature.

Fourth, the movement and positioning of the cobot might have influenced the task enjoyment. For instance, Arai et al. (2010) explained that the placement of a cobot within 2 meters of the operator and a moving speed of higher than 500 mm/s induces physiological and psychological stress. Stress could cause the operator to devaluate the task enjoyment since the cobot was placed within the recommended 2 meters. Still, the pace of the cobot was set at 500 mm/s and thus probably not of influence.

Fifth, the survey questions were not randomly shuffled between conditions was the exception to the RoSAS items. Possibly, the participants have answered in repetitive order but the conditions were offered randomly between each participant. Moreover, keeping the presentation of the survey constant directed extra attention to the differentiation between conditions instead of the survey itself. To be more precise about the RoSAS scale, the answers questions might have been primed by the collaboration cobot. The instructions to answer in the perspective of the *category* robot might have been too vague. Still, if participants were confused about the term category and whether it applies to the cobot or not, the more significant part of the participants verified what was meant with 'category robots'.

Sixth, the measurement of the stress probability has some elements which require mentioning. Even though the measurement tools for heart rate and skin conductance had no reasons to be questioned, the mere rest moments when waiting on cobot could have lowered the physiologically measured stress. Furthermore, the HUME model producing the stress probability has been trained on physiological stress moments induced by scaring people. The model is not trained on the cobot scenario and might therefore not be the right measurement tool. Arguably, the sensitivity needed to perceive significant differences between each condition might have been too low since the model is trained on more extreme scenarios. However, the healthcare application shows that this model provides a decent basis for interpreting the arousal level even though this specific application is likewise to the experiment a long-term influence. Furthermore, the ratio between the results of each condition is not altered due to the model. Future research is still advised to implement stress measurements as it is unclear the impact of robots collaboration, especially since earlier research indicates adverse effects.

6 Conclusion

The increase of technological applications in the working environment will be a constant for upcoming years in which cobots take their place. The collaborations with robots will become increasingly more complex, and therefore it is important to consider the human perspective. As described by the Self-Determination Theory, work autonomy is one of the essential pillars towards motivation in the work environment (Gagné & Deci, 2005). This study contributes to that pillar within the domain of human-robot interaction in two ways. First, this study shines a new light on the limited collection of research that discusses aspects of the Human Factor in industry 4.0, specifically for the application of cobots. It shows that collaboration with a high autonomy robot leads to adverse effects such as a decrease in task enjoyment and perceived task autonomy. Furthermore, this study is the first, to our knowledge, to have empirically investigated the effect of cobot autonomy on the individual's perceived autonomy. By testing with an actual cobot in an actual assembly, a valuable step has been made towards validation in a more ecologically appropriate environment. Second, this study shows a promising and simultaneously cautious view of robot assistance from a societal perspective. The idea of technological assistance and solutions to support human limitations is a very promising domain. Nevertheless, as the results might suggest, it is important to maintain a critical stand towards their implementation just for the beneficial point of view. When the human perspective is not considered, the potential of collaboration might not be reached as the motivation towards artificial agent collaboration or assistance can be negatively influenced.

So, what is the impact of a cobot's autonomy level (low to high levels of autonomy) in assembly on the perceived task autonomy of an operator? A worker who collaborates during an assembly with a low autonomy robot will experience more perceived task autonomy than a worker who collaborated with a high autonomy cobot. Moreover, the experience of task enjoyment as well as the perceived control decrease as the cobot has more autonomy. To conclude, the results suggest that autonomous functioning by a cobot must be used with caution in collaboration, especially considering the need for autonomy to motivate individuals to a specific behavior.

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Appendix

I. Survey

For each condition:

Dear participant,
Welcome. Below you will find a series of questions in relation to the AMS experiment. Please read each instruction and statement/question carefully and respond accordingly.

There are 4 questions in this survey.

Perceived task autonomy

Below you will find a series of statements. Please read each statement carefully and respond to it by expressing the extent to which you believe the statement applies to you. ***In your response to these statements, consider your activity as operator in your last finished assembly.*** For all items a response from 1 to 7 is required. Use the number that best reflects your belief when the scale is defined as follows.

1. Totally disagree
2. Disagree
3. Somewhat disagree
4. Neither agree or disagree
5. Somewhat agree
6. Agree
7. Totally agree

Statements:

1. I felt like I could be myself during this activity
2. During this activity, I often felt like I had to follow other people's commands (R)
3. If I could have chosen, I would have done things differently during the activity (R)
4. The things I had to do during this activity were in line with what I really wanted to do
5. I felt free to do the activity the way I think it could be done best

6. In this activity, I felt forced to do things I did not want to do (R)

Perceived control

Below you will find a series of statements. Please read each statement carefully and respond to it by expressing the extent to which you believe the statement applies to you. ***In your response to these statements, consideryour activity as operator in your last finished assembly.*** For all items a response from 1 to 7 is required. Use the number that best reflects your belief when the scale is defined as follows.

1. Not at all
2. No
3. Mostly not
4. Neutral
5. Mostly yes
6. Yes
7. Very much

Statements :

1. I felt that I was in control
2. I was able to approach the problem in my own way
3. I think a robot could recognize me and respond to me.
4. I think a robot would obey my commands.

Task enjoyment

Below you will find a series of statements. Please read each statement carefully and respond to it by expressingthe extent to which you believe the statement is true to you. ***In your response to these statements, consideryour activity as operator in your last finished assembly.*** For all items a response from 1 to 7 is required. Usethe number that best reflects your belief when the scale is defined as follows.

1. Not true at all

2. Not rue

3. Somewhat not true

4. Neutral

5. Somewhat true

6. True

7. Very true

Statements:

1. I enjoyed doing this activity very much
2. This activity was fun to do.
3. I thought this was a boring activity. (R)
4. This activity did not hold my attention at all.(R)
5. I would describe this activity as very interesting.
6. I thought this activity was quite enjoyable.
7. While I was doing this activity, I was thinking about how much I enjoyed it

Closing page:

Dear participant,

You have reached the end of the survey. Thank you for your time and effort. If you have any remaining questions regarding the survey or experiment, do not hesitate to ask the experimenter Stijn van Geffen(stijn.vangeffen@mentechinnovation.eu).

You may leave the laptop as is.

To finish the experiment, please ask to experimenter for the final instructions.

Final Survey:

Dear participant,

Welcome. Below you will find a series of questions in relation to the AMS experiment. Please read each instruction and statement/question carefully and respond accordingly.

There are 5 questions in this survey.

Robot Perception

Below you will find a series of statements. Please read each statement carefully and respond to it by expressing ***how closely are the words below associated with the category robots?***. For all items a response from 1 to 7 is required. Use the number that best reflects your belief when the scale is defined as follows.

1. Definitely not associated
2. Not Associated
3. Somewhat not associated
4. Neutral
5. Somewhat associated
6. Associated
7. Definitely associated

Statements (randomized):

Happy

Feeling

Social

Organic

Compassionate

Emotional

Capable

Responsive

Interactive

Reliable

Competent

Knowledgeable

Scary

Strange

Awkward

Dangerous

Awful

Aggressive

Desirability of Control

Below you will find a series of statements. Please read each statement carefully and respond to it expressing ***the extent to which you believe the statement applies to you.*** For all items a response from 1 to7 is required. Use the number that best reflects your belief when the scale is defines as follows.

1. Not at all
2. No
3. Mostly not
4. Neutral
5. Mostly yes
6. Yes
7. Very much

Statements:

1. I prefer a job where I have a lot of control over what I do and when I do it.
2. I enjoy political participation because I want to have as much of a say in running government as possible.
3. I try to avoid situations where someone else tells me what to do.
4. I would prefer to be a leader rather than a follower.
5. I enjoy being able to influence the actions of others.
6. I am careful to check everything on an automobile before 1 leave for a long trip.
7. Others usually know what is best for me.
8. I enjoy making my own decisions.
9. I enjoy having control over my own destiny.
10. I would rather someone else took over the leadership role when I'm involved in a group project.
11. I consider myself to be generally more capable of handling situations than others are.

12. I'd rather run my own business and make my own mistakes than listen to someone else's orders.

13. I like to get a good idea of What a job is all about before I begin.

14. When I see a problem I prefer to do something about it rather than sit by and let it continue.

15. When it comes to orders, I would rather give them than receive them.

16. I wish I could push many of life's daily decisions off on someone else.

17. When driving, I try to avoid putting myself in a situation where I could be hurt by someone else's mistake.

18. I prefer to avoid situations where someone else has to telt me what it is I should be doing.

19. There are many situations in which I would prefer only one choice rather than having to make a decision.

20. I like to wait and see if someone else is going to solve a problem so that I don't have to be bothered by it.

DEMOGRAPHICS

What is your age?

……………………………

What is your gender?

- Male
- Female
- Non-binary
- Prefer not to disclose
- Prefer to self-describe (please fill in in the comment section)

Education level

- What is the highest level of education you have finished?
  - Less than high school

- High school
- 2 years college degree (associates)
- 3/4-years college degree (BA, BS)
- Master's degree (MA, MS)
- Education Doctoral degree (PhD)
- Professional degree (MD, JD)
- Other

Closing page:
Dear participant,

You have reached the end of the survey. Thank you for your time and effort. If you have any remaining questions regarding the survey or experiment, do not hesitate to ask the experimenter Stijn van Geffen(stijn.vangeffen@mentechinnovation.eu).

You may leave the laptop as is. To finish the experiment, please ask to experimenter for the final instructions.
Thank you for completing this survey.

II. Assembly Process

Step 1:

Step 2:

Step 3:

Step 4:

Step 5:

Step 6:

Step 7:

Completed:

Tool for assembly: