Original Article

Information Processing in Work Environment 4.0 and the Beneficial Impact of Intentional Forgetting on Change Management

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Abstract: Industry 4.0, based on increasingly progressive digitalization, is a global phenomenon that affects every part of our work. The Internet of Things (IoT) is pushing the process of automation, culminating in the total autonomy of cyber-physical systems. This process is accompanied by a massive amount of data, information, and new dimensions of flexibility. As the amount of available data increases, their specific timeliness decreases. Mastering Industry 4.0 requires humans to master the new dimensions of information and to adapt to relevant ongoing changes. Intentional forgetting can make a difference in this context, as it discards nonprevailing information and actions in favor of prevailing ones. Intentional forgetting is the basis of any adaptation to change, as it ensures that nonprevailing memory items are not retrieved while prevailing ones are retained. This study presents a novel experimental approach that was introduced in a learning factory (the *Research and Application Center Industry 4.0*) to investigate intentional forgetting as it applies to production routines. In the first experiment ($N = 18$), in which the participants collectively performed 3046 routine related actions (t1 = 1402, t2 = 1644), the results showed that highly proceduralized actions were more difficult to forget than actions that were less well-learned. Additionally, we found that the quality of cues that trigger the execution of routine actions had no effect on the extent of intentional forgetting.

Keywords: intentional forgetting, retrieval cues, production routine

Informationsverarbeitung in der Industrie 4.0 und die vorteilhafte Wirkung von intentionalem Vergessen für das Change Management

Zusammenfassung: Industrie 4.0 ist basierend auf fortschreitender Digitalisierung eine globale Entwicklung, die in allen Bereichen uns heute bekannter Arbeits- und Lebenswelten Einzug halten wird. Das Internet der Dinge beschleunigt Automatisierung bis hin zu autonomen cyber-physischen Systemen. Dieser Prozess wird begleitet von einer weiteren Zunahme von Daten. Gleichzeitig reduziert sich die Aktualität der Daten und damit die Dauer ihrer Relevanz. Die Herausforderungen im Umfeld von Industrie 4.0 zu meistern bedeutet für Menschen in Organisationen diese wachsenden Datenmengen und Anpassung an fortwährende Veränderung zu bewältigen. Intentionales Vergessen kann hier unterstützen. Intentionales Vergessen fokussiert das Vergessen irrelevanter Informationen und Verhaltensweisen zu Gunsten relevanter. In diesem Artikel stellen wir einen experimentellen Ansatz zur Erforschung von Prozessen des intentionalen Vergessens in Organisationen in einer Laborumgebung (*Anwendungszentrum Industrie 4.0*) vor. Im Fokus der Untersuchung steht dabei das Vergessen einer ungültig gewordenen Produktions-Routine und das Ausführen der neuen, jetzt gültigen. Wir beschreiben dabei zunächst das innovative experimentelle Design zur Untersuchung von Vergessensprozessen. In einer ersten Untersuchung mit $N = 18$ Personen, die insgesamt 3046 Handlungen zu t1 (1402) und t2 (1644) ausführen, zeigte sich, dass hoch gelernte (prozeduralisierte) Handlungen schwerer zu vergessen sind als ohnehin nicht prozeduralisierte. Es zeigt sich aber kein Unterschied hinsichtlich der Art der Handlungen und der Hinweisreize, durch die sie aufgerufen werden.

Schlüsselwörter: Intentionales Vergessen, Produktions-Routine, Hinweisreize

Digitalization – A Change Driver for Adaptation in Production Processes

Digitalization and the emergence of technologies associated with Industry 4.0 are key drivers of change in almost every organization and area of work (Jacobs, Kagermann, Sattelberger, & Lange, 2018). *Digitalization* and *Industry 4.0* are umbrella terms that cover several current and future technologies that will affect everyday work and manufacturing conditions (Hämmerle, Pokoni, & Bertold, 2018). They are perceived as genuine technological innovations, and as such belong to one of the classic

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change drivers in organizational science (Hatch & Cuncliff, 2013). According to the theory, organizations have to change in order to maintain their organization–environment fit in the technology-driven and fast-changing world around them (Huber, 2011).

Digitalization is typically characterized by two major phenomena: (a) the individualization of products and services, and (b) the growing need to deal with increasing amounts of information (Baker, 2012). Both phenomena are relevant to production processes, which form the core of this article. Whereas over the past century industrial production processes were characterized by production routines yielding a large number of identical products through mass production, the future-claimed benchmark of digitalization and Work 4.0 is the *Lot Size One* concept (Werther, & Bruckner, 2018).

The purpose of the present study is to propose intentional forgetting as a solution to the need for flexibility. We therefore presented an experimental design that makes intentional forgetting measurable and translates theoretical assumptions (Kluge & Gronau, 2018) into a real production process. We understood intentional forgetting as a motivated and planned process of suppression of the recall of memory items and as the inhibition of the retrieval process to avoid memory items being made available for current use in production routines (Kluge & Gronau, 2018).

Lot Size One: Only the Knowledge About the Actual Production Process Matters

Both features of digitalization – individualization of production processes and the need to deal with drastically increasing information – stress the challenges of ambivalent information processing. The absolute amount of relevant data and knowledge increases with every new production alternative, whereas the relevant knowledge for a particular, single-production item becomes more specific as the amount of product variance increases. Knowledge and operations, which are part of the production process but are currently irrelevant in a different context, should not be implemented but should instead be "forgotten" temporarily and should depend on the current demands of the production process. The way in which workers and operators manage currently irrelevant knowledge and action is the focus of research concerning intentional forgetting in organizations (Ellwart & Antoni, 2017; Fiol & O'Connor, 2017; Kluge, Schüffler, Thim, Vladova, & Gronau, 2018).

Retrieval Theories of Forgetting and Production Routines – The Theoretical Background

Forgetting from a cognitive psychology perspective is not a malfunction in human information processing (Roediger, Weinstein, & Agarwal, 2010; Wixted, 2004, 2005), but rather an essential adaptive function in suppressing and sorting out information that is no longer up-to-date (Bjork, 1998). The human brain does not actually delete obsolete knowledge, but it is able to not recall it or to suppress it. If one's environment changes, then adaptability is required, meaning that previous objectives need to be forgotten so as to allow one to focus on currently relevant objectives (Altmann & Gray, 2002; Roediger et al., 2010). This requirement also applies to organizations facing changing environments. To successfully change and adapt, it is often necessary to forget or unlearn things, as well as acquire and disseminate new knowledge (Kluge & Schilling, 2003, 2004; Nonaka & Takeuchi, 1995; Schilling & Kluge, 2009). Our approach to forgetting in the context of organizations focuses on the need for business processes that deliberately impede the recall of certain organizational memory items as a way to support an organization's changed strategic goal achievement (Kluge & Gronau, 2018). In particular, the focus is on *intentional* forgetting, which is defined as a motivated attempt to limit the future recall of a memory item (Bjork, Bjork, & Anderson, 1998; Johnson, 1994), motivated, for example, by the need to achieve an individual or group-level strategic goal. Intentional organizational forgetting is a motivated and planned suppressive process of organizational memory items and the inhibition of the retrieval process in order to avoid memory items being made available for current use (Ellwart & Kluge, 2019; Kluge & Gronau, 2018). Other concepts of motivated or directed forgetting focus on motivational aspects and neural as well as cognitive functions as highly individual processes (Anderson & Hanslmayr, 2014).

In this study, we built on retrieval and cue-dependent forgetting theories, as they constitute a suitable theoretical basis to manage forgetting on the organizational, team, and individual level. Our operationalization of intentional forgetting is based on retrieval theories, which explain forgetting in terms of cue overload, cue availability, consolidation, and repression, and propose that recall is triggered by cues (Gronlund & Kimball, 2013; Nairne & Pandeirada, 2008; Roediger et al., 2010). Our work revolves around the assumption that forgetting results from changing cue conditions. If cues that are needed for recall are not present in a particular situation, then cue-dependent forgetting will result (Tulving, 1974). Following this theoretical approach, the forgetting of an individuum depends not only on individual intrapersonal processes (Anderson & Hanslmayr, 2014), but also on the factual elimination of a retrieval cue. As regards production-routine changes, it is objectively clear what a behavioral adaptation has to look like, which elements on the level of singular action have to be recalled, and which have to be forgotten.

Within this setting, it does not matter whether the working individual himself or herself, or the team or organization, replaces relevant retrieval cues to enable the individual to forget unnecessary behavior. In such a case, the intention to forget mirrors the intention to change the production process and adapt behavior, and it can be managed on all organizational levels as an objective observable process by replacing relevant retrieval cues. In our understanding of intentional forgetting, the intention to forget might on the one hand relate to the intentions of a working individual aiming to do a good job, and on the other to the intentions of a team or an entire organization managing a change successfully.

If a particular cue is missing over a longer period, resulting in no recall of it, then forgetting will materialize, as the retrieval strength of the memory item associated with the retrieval cue is reduced (Bjork, 2009; Bjork & Bjork, 1992, 2006). Retrieval strength represents the accessibility of particular memory items. Accessibility can be differentiated in terms of storage strength and retrieval strength. The former describes the thoroughness with which a memory item is stored and anchored in memory. Memory items with high storage strength might have low retrieval strength due to longer periods of non-use. Whether or not a memory item is recalled depends on its retrieval strength. In a nutshell, as recall is cue-dependent, the absence of retrieval cues can result in reduced retrieval strength (for a detailed description of this concept, see Kluge & Gronau, 2018).

Organizational forgetting (e.g., Martin de Holan, 2011; Martin de Holan & Phillips, 2004; Martin de Holan, Phillips, & Lawrence, 2004) and unlearning (e.g., Hedberg, 1981; Tsang & Zahra, 2008) have a long tradition of theoretical discussion about their value and importance to organizational learning and change (Kluge & Gronau, 2018). In terms of scientific discussion, the unlearning and forgetting of routines play a prominent role. Researchers who have investigated organizational forgetting (Martin de Holan et al., 2004; Martin de Holan & Phillips, 2004) have stressed the impact of routines on organizations' stability and ability to change. Tsang and Zahra (2008) and Miller, Pentland, and Choi (2012) concluded that adaptation in organizations requires the forgetting of routines (Miller et al., 2012). Organizational routines are defined as "multi-actor, interlocking, reciprocally-triggered sequences of actions" (Cohen & Bacdayan, 1994, p. 554). The defining characteristics of routines include repetitive and consistent perceivable action patterns (Becker, 2004; Gersick & Hackmann, 1990) and mutually dependent/interdependent actions, performed by several actors (Becker, 2004; Pentland & Hærem, 2015).

The smallest unit within a routine performed by a human operator is a single action (see next section). From the viewpoint of a technical change process, an action has to be changed in order to change the routine. On the part of the human operator, he or she has to adapt his/her performance to meet the changed requirement and perform the changed action in a proper manner and without errors. In the following sections, we use the term *change* in relation to actions, and *adaptation* in relation to human operators' behavior (Figure 1).

The ideal execution of a routine on an individual level implies that the actions that form that routine are performed with high proficiency, in other words "automatically" (Schneider, 1985, 1999; Wickens, 2000), meaning quickly and without an excessive use of cognitive resources and awareness. However, this notion adds to the difficulty for a human operator to inhibit or forget the execution of a highly automated action, as part of a routine, and to consciously perform a different action to adapt to a new routine.

Figure 1 presents the possible ways in which routine action can change. The pearls stand for types of action that form a routine. In Scenario 1, actions are in the order in which they need to be executed. In Scenario 2, an individual action is changed qualitatively (e.g., by measuring in inches instead of centimeters). In Scenario 3, a particular action is deleted (e.g., marking relevant information in a work plan), making the routine shorter. In Scenario 4, an action is added to the routine (e.g., using a new safety lock), making the routine longer.

Combining both theoretical backgrounds (retrieval-induced forgetting and organizational forgetting), we assumed that the elimination of cues will weaken the retrieval strength of a routine's memory items and will therefore induce forgetting insofar as the memory item is not activated because the related situational, sensory, or routine-related cues are not present. Transferring the findings on the effects of the elimination of retrieval cues to an organizational context, we elaborated on three cue types that are considered important in the forgetting of organizational routines (Kluge & Gronau, 2018):

1. Sensory cues, which are basal cues, such as visual, olfactory, oral and tactile cues;
2. Routine-related cues, which include actor-related, object-related, sequence-of-task-related, and information-related cues; and

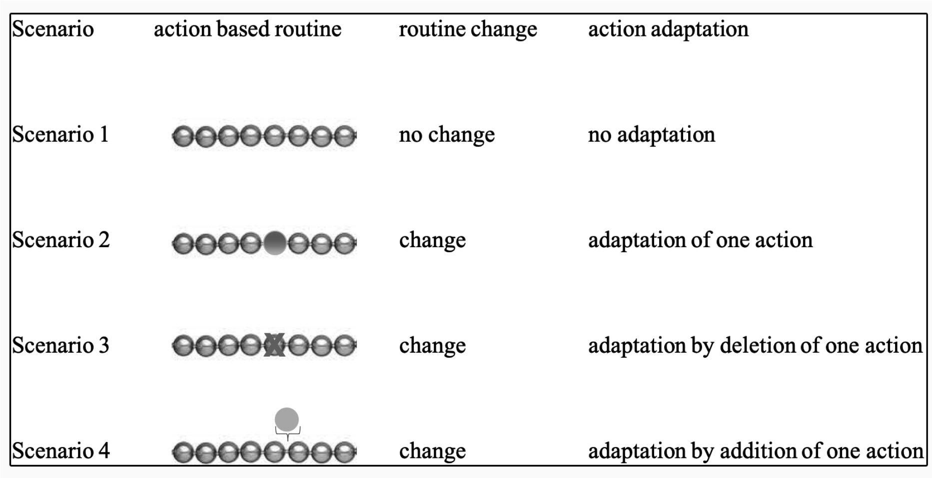

Figure 1. Illustration of possible scenarios of action adaptation based on routine changes.

3. Time and space cues, which include stimuli indicating the location (e.g., production site) and time (of year, week, day) of the execution of a routine.

Generally, it is assumed that sensory and routine-related retrieval cues associated with a formerly valid but now invalid routine need to be eliminated in order to stop the recall and retrieval of the old routine (Kluge & Gronau, 2018).

Taking the assumptions regarding intentional forgetting and routine-related retrieval together, we assumed that:

A single routine action is associated with particular retrieval cues, which activate that action's recall. As retrieval cues can differ in quality (e.g., category), we took account of differences in their impact on the intentional forgetting of an action that is dependent on the category.

Hypothesis 1: Intentional forgetting (measured in terms of errors regarding the retrieval of actions that should be forgotten) differs depending on the category to which the relevant retrieval cue belongs.

On the basis of the relevance of retrieval strength, we assumed:

Hypothesis 2: The intentional forgetting of an action depends on the proficiency level with which the action has formerly been executed. Action that has been performed with a high level of proficiency is associated with a higher retrieval strength and is therefore more difficult to forget after a change, compared with an action that has been performed with less proficiency (lower retrieval strength).

Method

This study was conducted between January and March 2018 at the Research and Application Center Industry 4.0 (RACI) of the University of Potsdam. In the study, we focused on routine actions carried out by 18 participants at two measurement points (t1 and t4), with additional learning activities in-between (t2, t3).

Sample. In total, 18 persons (six female, age M = 29.00, SD = 9.65; 11 male, age M = 30.82, SD = 8.94, and one man without age documentation) participated in the study. The study was approved by the Ethics Committee of the Faculty of Psychology at the Ruhr-Universität Bochum. The participants were informed about the general set-up of the study and assured that they could discontinue their participation at any time (through their informed consent). All of the participants were novices in terms of learning the multi-actor routine at RACI and received 40 EUR for their participation on all four occasions. They were recruited through postings in Internet forums and on the social media platforms of the University of Potsdam, and also through flyers handed out on campus and during lectures.

General Set-Up of the Study

To test our hypotheses, we used a special-purpose setting (Stone-Romero, 2011). A special-purpose setting can be a laboratory that is equipped as a production setting, or an industrial site that is used for experimental studies (Kluge et al., 2018), which have been created for the specific purpose of conducting research (Stone-Romero, 2011). Special-purpose settings cease to exist when the research has been completed and are designed to enable intentional manipulation of the independent variables. In the present study, we used a special-purpose setting called the Research and Application Center for Industry 4.0 at the University of Potsdam (Figure 2, Kluge et al., 2018).

Figure 2. The special-purpose setting Research and Application Center for Industry 4.0 (RACI) at the University of Potsdam, which was used for the study on retrieval cues, as described in the text.

The Research and Application Center for Industry 4.0

The Research and Application Center for Industry 4.0 (RACI) provides a hybrid production simulation where hardware equipment (e.g., transportation systems, manufacturing robots, QR scanners) is enriched with software components (Gronau, Theuer, & Lass, 2012). Participants can experience the physical, visual, and audible effects of their interaction (Gronau et al., 2012). By using industrial components and footage from a real production environment, it is possible to re-enact modified real-world processes, which in our case concerns the production of knee joints. In the special-purpose environment of RACI, machines and workpieces are simulated as software components running on "cubes" – small computers with three displays (Figure 3). The machines have an interface so that participants can start and monitor certain production steps, for example, selecting a production program. The interaction is followed by audible or visual effects or the start of a physical component, such as a robotic arm. The relevant environmental information is delivered through various sensors (Gronau et al., 2012).

The Multi-Actor Routine and the Production Process

At RACI, artificial knee joints are produced in groups comprising three workers. Knee joints were chosen for this study because they need to be produced at a very high-quality standard by following a predefined procedure and are unique for each customer. In the experiments, the participants (in three-person worker teams) came to RACI twice:

- Week 1 (t1, training to perform the multi-actor routine pertaining to the worker's position: milling, polishing, or disinfecting without errors in a predefined time period)
- Week 4 (t4, time to intentionally forget the actions of the previously learned routine and to carry out the changed actions of the new prevailing routine)

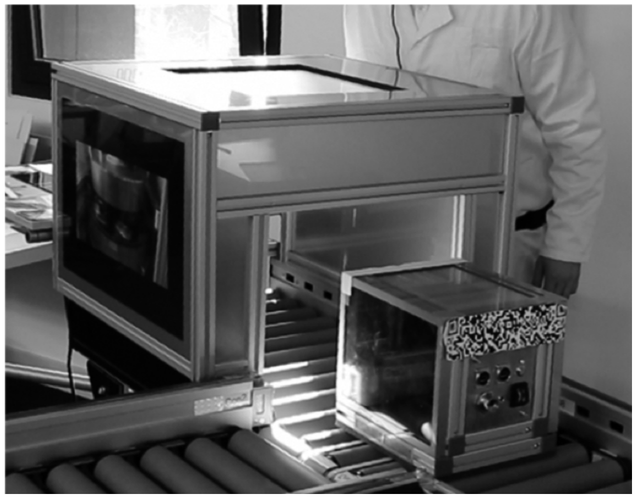

Figure 3. A machine cube (on the left side of the figure) and a workpiece cube (on the right side).

The three worker positions and the related routines were named differently, but the number and characteristics of the routine's actions (e.g., the buttons to be pushed on the cube) were identical:

- The routine of each worker included eight steps (e.g., obtaining the work plan, controlling the workpiece, etc.). Each step consisted of a maximum of six individual actions.
- *Actions* were the smallest units to be measured and executed (e.g., deciding which work plan to use, searching for the work plan within a list). Each worker had to carry out 33 actions that formed the routine of the worker's position (milling, polishing, or disinfecting).
- The 33 actions were performed by three workers each, which meant that the workers collectively performed a total of 99 actions in order to jointly carry out the multi-actor routine.
- For the present study, 45 actions (out of the 99 actions performed by the three-person worker teams) were of interest, and these 45 actions were changed between t1 and t4. These 45 actions performed at t1 were the ones that needed to be forgotten at t4 (the remaining 44 actions stayed unchanged from t1 to t4).

Experimental Procedure. After a learning phase lasting approximately 30 min, including the execution of the production process three times for training purposes, the subsequent production phase took approximately 40 min. During this period, a maximum of eight artificial knee joints could be produced without errors.

After Week 1 (t1), the participants practiced further the execution of their worker position routine in Weeks 2 (t2) and 3 (t3) with the support of an app (Figure 4) designed to increase the storage and retrieval strength of the actions and to ensure that the routine had been well learned.

Figure 4. Training app to maintain high retrieval strengths of actions.

In Week 4 (t4), the participants returned to RACI expecting to carry out the same routine that they had trained for over 3 weeks. However, they were informed that due to a merger with an American company, certain routine-related actions had been changed, for example, they now had to use imperial measures, such as inches instead of centimeters. In total, around 50 % of the routine needed to be forgotten (see previous section, 45 out of 99 actions). An overview of the experimental set-up is given in Figure 5 and Table 1.

The specific length of time between t1 and t4 (21 days) was chosen in order to ensure that the additional app training would allow the workers to reach a level of proficiency in performing the routine learned at t1. This period of time was kept equal for all the participants. Moreover, all training material used at RACI was standardized (e. g., video instruction) to avoid effects caused by different experimenters.

As can be seen in Table 1, we also measured person-related variables and control variables, but these are not the focus of the present article.

At the center of our analysis are the actions of the multi-actor routine. The executions of the modified 45 actions were counted:

- At t1 (a total of 1402 times), and
- At t4 (with changed routine) (a total of 1644 times; see Table 2).

Taking t1 and t4 together, we analyzed 3046 actions. The higher number at t4 is due to the fact that the completed routines were executed more often.

Variables

Independent Variables

In the present study, we focused on two independent variables: retrieval cues (Hypothesis 1), and the level of proficiency in action execution at t1 (Hypothesis 2).

Action-related retrieval cue: Actions could be distinguished from their related retrieval cue category because every action could be defined as a single, specific action or behavior associated with one of the three cue categories: "on the cube display," "around the machine," and "documentation material" (testing Hypothesis 1).

The place and tool for executing an action were the significant criteria required to differentiate certain categories. The places and tools within each category formed a stable combination, which differed between the categories. With each categorized combination of place and tool, only specific actions could be executed. Therefore, places and tools were highly relevant retrieval cues for their associated specific actions (e. g., on the cube display was a specific place that allowed for the operation of a machine using push-buttons, and it was not possible to operate the machine at another place or in another manner, as

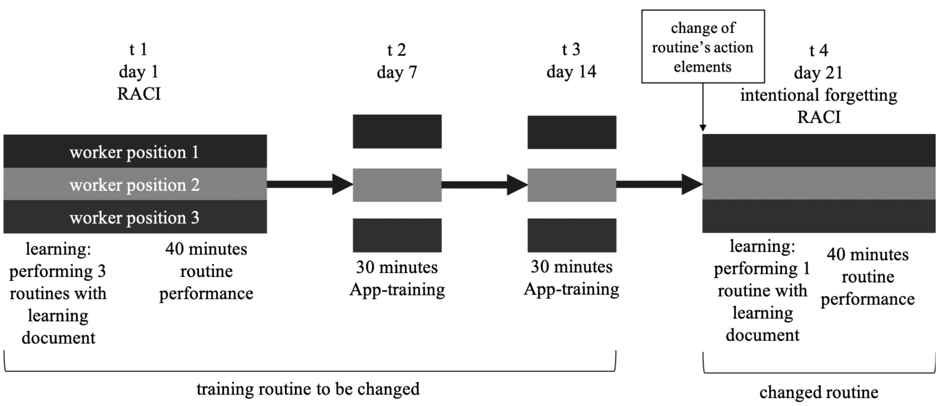

Figure 5. General experimental setup (RACI = Research and Application Center Industry 4.0).

Table 1. Structuring of t1 and t4 with scheduled times

t1 (at RACI)		t4 (at RACI)	
Welcoming of participants with an explanation and introduction	*Instruction Video 6:31*	Welcoming of participants with explanation of changes and introduction	*Instruction Video 5:52*
		Signing non-disclosure agreements and filling in questionnaires	*10 min*
Signing informed consent forms and filling in questionnaires (assessing person-related variables)	*10 min*	Equipping with mobile eye-tracker	*10 min*
Equipping with mobile eye-tracker	*10 min*	Performing one changed routine with learning documents	*15 min*
Performing three routines with learning documents	*30 min*		
Performing production routines (without learning documents)	*40 min*	Performing production routine (without learning documents)	*40 min*
Filling in questionnaires (person-related variables, e.g., self-efficacy)	*10 min*	Filling in questionnaires (e.g., presence, satisfaction)	*25 min*

Note. RACI = Research and Application Center Industry 4.0.

pushing the buttons on the display was only effective at this place for that purpose). Based on the retrieval theories mentioned earlier, it was assumed that different categories of retrieval cues would differ in terms of their influence on forgetting actions that were associated with them.

Actions on the cube display: The category of actions on the cube display encompassed all actions that took place in direct contact with the production site. All of these actions included the operating of the manufacturing plant by pushing a specific button on a touchscreen of a terminal of the plant (Figure 6). These actions were measured with log files produced by the machine.

Under the altered conditions of t4, other keys on the interface or push-buttons had to be selected, and different program parameters had to be used (e.g., t1: programs 1–3, t4: programs 4–6, presented on the display with specific names for each program).

Figure 6. Interaction via the real interface of the demonstrator (cube) of the knee joint produced in the special-purpose setting.

Actions around the machine: The actions around the machine differed most between worker positions, as this category concerned position-dependent individual actions that represented the uniqueness of each worker's production process sequence (Worker 1 had to carry the workpiece, Worker 2 had to handle a polisher, Worker 3 had to use packaging material; Figure 7). These actions were recorded using eye-tracking data, as each worker was wearing a mobile eye-tracker.

Figure 7. Interaction with a workpiece around the machine.

Actions with the documentation material: The actions associated with documentation included writing, noting, or annotating something on a prepared piece of paper. The participants used pencils or stickers (Figure 8). All of these actions were counted by reading them from the document itself.

Under the altered conditions of t4, some annotations and notifications were not required anymore, and some of the items that needed annotation changed, or the way in which they had to be marked was changed (e. g., pens vs. sticky dots).

Figure 8. Actions with the documentation material.

Proficiency level of action executions at t1: As an independent variable (Hypothesis 2), we measured how proficiently the to-be-changed actions were carried out at t1. We measured the proficiency level in terms of the number of errors, with the execution of actions with a low error rate representing a high proficiency level, and vice versa. It was assumed that actions being executed with high proficiency were learned well and had high retrieval and storage strength (Kluge & Gronau, 2018).

Dependent Variables

As the dependent variable, we measured intentional forgetting in terms of relative errors made while performing actions in t4 that had been changed between t1 and t4. Relative errors were operationalized as the number of actions executed at t4 that had been changed, in relation to the total executed routines in t4. A relative error equaling zero represented a correct intentional forgetting performance with no errors.

Errors were counted by means of log file analysis, by identifying errors in the sequence of routine executions performed by the three worker positions (i.e., executed actions of the invalid routine), by means of gaze data, since all of the participants wore eye-trackers to identify what they were looking for, and by means of reading out the documents in order to identify wrong marks (Kluge et al., 2018).

Measurement and Data Analysis

Measuring forgetting entails certain challenges (e. g., distinguishing forgetting from other kinds of error), which are addressed in the following section.

Measuring intentional forgetting in the present paper requires that each executed action at t1 and t4 is grouped into one of four categories:

1. A correct action according to the prevailing routine;
2. A wrong action according to the prevailing and the nonprevailing routine;
3. A correct action according to the routine that is nonprevailing (in the case of t4 according to the routine of t1, and in the case of t1 according to the routine of t4); and
4. Neutral – a category for classifying behavior that could not be interpreted as distinct within the framework of the experiment. This category included action that was neither correct nor wrong in terms of the prevailing and nonprevailing routine, and was simply not designated (e. g., a worker moving about the laboratory without any identifiable target).

The distinction between the prevailing and nonprevailing routine was introduced to make clear to which routine an assessment of errors belonged, because *error* in this study was defined in relation to the routine-related action required.

Actions that had been changed had to be performed correctly at t4. At t4, a correct performance represented a correct adaptation, and therefore it represented forgetting (e. g., measuring in inches, correct in t4, and not in centimeters, which would have been correct in t1). Where the adaptation consisted not of an action but of an omission, the action was correctly forgotten if its execution was suppressed (e. g., marking relevant information [correct in t1] no longer being required in t4).

A correct performance according to the nonprevailing routine at t4, meanwhile, implied that a worker had not forgotten what was supposed to be forgotten (e. g., measuring in centimeters, marking relevant information). If an observed action was neither correct in terms of the routine at t1 nor in terms of the routine at t4, it was classified as *neutral*. This neutral classification was applied in cases where actions were performed partly correctly in terms of the prevailing routine and partly correctly in terms of the nonprevailing one (e. g., carrying out a nonaltered action with an altered instrument), or where the performance of the action could not be classified as being free of doubt. A neutral classification automatically led to an exclusion from further analysis.

Table 2. Number of performed actions by category and routine condition at t1 and t4

Category	Number of different actions in each category	Number of single actions at t1 per category	Number of single actions at t4 per category
On the cube display	7	272	318
Around the machine	12	123	194
Documentation material	26	1007	1132
Sum	45	1402	1644

Table 3. Mean number of routines performed (t_1, t_4), mean time for performing one routine (t_1, t_4), mean time for performing the last routine (t_1, t_4))

	M_{t1} (*SD*)	M_{t4} (*SD*)	*Diff.* M_{t1-t4} (*SD*)	*t* (*df* = 17)	*BCa* 95 %, *CI* 95 % *lower*	*BCa* 95 %, *CI* 95 % *upper*
Performed routines	6.28 (1.32)	6.56 (1.29)	-0.28 (1.45)	-0.81	-0.99	0.44
Mean time (min) per routine	12:42 (2:22)	9:54 (2:07)	2.80 (1.24)	9.56**	2.18	3.41
Mean time (min) of last routine	7:40 (2:22)	6:37 (1:37)	1.05 (3.12)	1.42	-0.50	2.60

Note. Diff. M_{t1-t4} and *t* values of a paired-samples *t* test; bootstrapping interval: *BCa* 95 %, *CI* 95 % *lower*; *BCa* 95 %, *CI* 95 % *upper*. ** $p < .01$.

Technical Aspects of Measurement

The log files were saved on the server that controlled the IT parts of the manufacturing plant. This server saved a list of standardized actions sorted by time of initiation. Each entry in the list was a result of an action on the machine. During the analysis, each entry written into the log file was classified either as correct or wrong according to the prevailing routine, or correct according to the nonprevailing routine, or neutral (see explanation in previous section). For the log file analysis, DALAS (diagonal adjusted log file analyzing structure) was used, whereby the real log file data of each production routine sequence was juxtaposed with the expected and ideal log file data of that routine. The tool was able to classify each entry within the log file according the introduced scheme.

Actions around the machine assessed by gaze search analysis (measured by gaze data): The participants wore mobile eye-tracking devices (SMI ETG 2W) that continuously recorded their gaze direction during the production process. Apart from the gaze data, the eye-tracking devices also recorded the participants' view. Analyzing those records allowed the researchers to analyze all the action that could not be documented via documentation or log files. This was particularly the case with actions around the machine. As a first step, the eye-tracking records were analyzed using SMI BeGaze Analysis Pro 3.6, and all the relevant actions were transcribed. As a second step, the transcribed actions were juxtaposed with the description of the actions in the learning document for the participants and based on that they were rated according the introduced scheme.

Documentation material analysis: Documentation-related actions were counted and analyzed by comparing what the participants wrote or drew in the particular documents (e.g., confirming a state, noting a measure). Therefore, reading out those documents and juxtaposing each annotation with the correct marked pattern allowed an assessment to be made of each documented action. For the documentation material, the actions were identical for all the worker positions (e.g., all the participants had to mark the same relevant information in t1 on their specific page of the work plan but did not have to mark any information in t4).

Results

The descriptive statistics are displayed in Tables 2 and 3. Looking at all the performed routines required to produce the knee joints, at t1 the mean of performed routines was $M = 6.28$ ($SD = 1.32$), and at t4 $M = 6.56$ ($SD = 1.29$). Table 2 shows the number of performed actions by category in greater detail.

Table 3 shows the average number of routines performed, the average time in which a routine was performed, the mean time for completing the last routine, and the number of overall relative errors.

As Table 3 shows, the mean time for completing a routine decreased from t1 to t4. In other words, routines were performed significantly more quickly at t4.

Testing the Hypotheses

Hypothesis 1 assumed that intentional forgetting (measured in terms of the retrieval of actions that should have

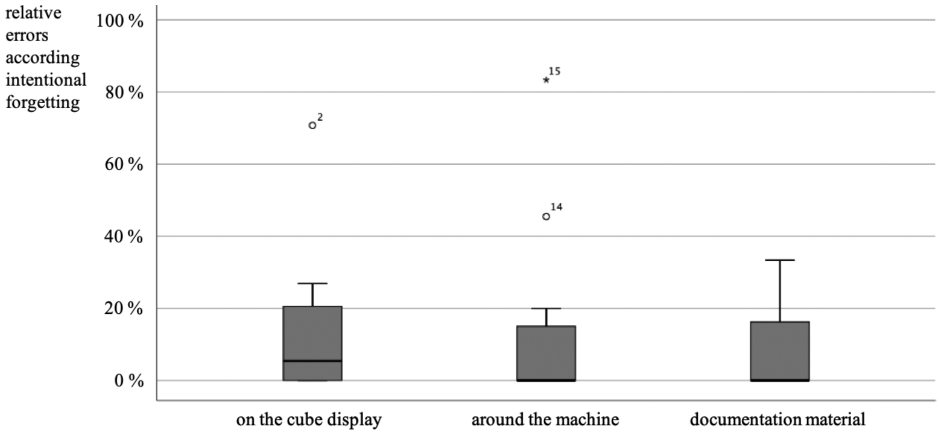

Figure 9. Box and whisker diagram for relative errors made according to intentional forgetting (t4) for the three action-cue-associated categories: on the cube display, around the machine, and documentation material.

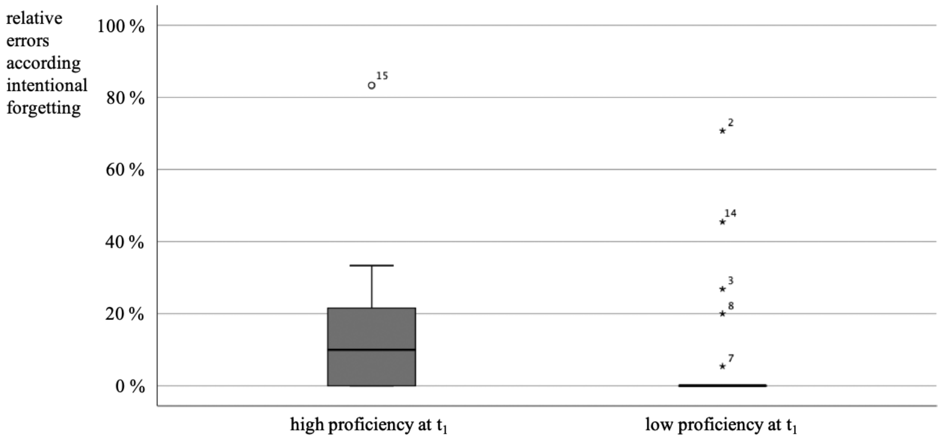

Figure 10. Box and whisker diagram for relative errors made according to intentional forgetting (t_4) for actions with high and low proficiency at t_1.

been forgotten) would differ based on the category to which the relevant retrieval cue belonged. An overview of the distribution of the different categories is given in Figure 9.

To test Hypothesis 1, Friedman's ANOVA for non-parametric tests of paired samples was applied. The factor cues category included three levels (on the cube display, around the machine, on the documentation material).

There was no significant effect of relative errors in terms of intentional forgetting on the levels of categories, χ^2_F (2) = 2.31, p = .31. The relative errors in terms of intentional forgetting (on the cube display: M = 0.17, SD = 0.26; around the machine: M = 0.14, SD = 0.26; documentation material: M = 0.08, SD = 0.12) did not differ significantly.

Hypothesis 1 had to be rejected and shows that action-cue-associated categories do not affect intentional forgetting errors per se.

Hypothesis 2 assumed that intentional forgetting of an action would depend on the proficiency level with which that action had been executed previously. To test Hypothesis 2, the actions were grouped based on a median split, and the actions performed with high proficiency and low proficiency at t1 were distinguished. An overview of the distribution of the actions within the two groups is given in Figure 10.

In order to compare the groups of actions at t4, a paired-samples t test was performed. A median split (Mdn = 0.19) was applied based on the measurement of relative errors of to-be-changed actions at t1. These 45 actions were divided into action performed with high proficiency at t1 (n = 23, M = 0.05, SD = 0.07) or low proficiency at t1 (n = 22, M = 0.47, SD = 0.12). The two groups differed significantly according to the criteria at t1, $t(43) = -14.16$, $p < .01$.

On average, actions that were changed between t1 and t4, and which were performed with high proficiency at t1, were performed with more relative errors in terms of intentional forgetting at t4 (M = 0.14, SD = 0.19). This difference (0.09, BCa 95% CI [0.01, 0.17]) was significant: $t(22) = 2.24$, p = .03.

Actions that were changed and were performed with less proficiency at t1 were executed with fewer relative errors in terms of intentional forgetting at t4 (M = 0.08, *SD* = 0.18). This difference (–0.39, BCa 95 % CI [–0.50, –0.28]) was significant: $t(21) = -7.32$, $p < .01$. Hypothesis 2 can thus be maintained.

Discussion

The purpose of the present study was to propose intentional forgetting as a solution to the need for flexibility. We presented an experimental design, outlined to make intentional forgetting measurable. We understood intentional forgetting as a motivated and planned process of suppression of the recall of memory items and as the inhibition of the retrieval process to avoid the availability of nonprevailing memory items for current use in changed production routines.

On the basis of our results, we see that our general experimental set-up was justified, as it was able to identify the processes and the results of successful and unsuccessful intentional forgetting. Owing to well-defined actions that constituted the production process routines, we were able to examine for every relevant action whether the adaptation of the behavior was successful. We could thus establish whether the necessary intentional forgetting took place. In a presumably ecologically valid manner, we were able to maintain our second hypothesis, as our experimental set-up confirmed one of the major claims of retrieval theories: Memory items with higher levels of proficiency can be assumed to have a higher retrieval strength and are consequently more difficult to forget (Kluge & Gronau, 2018).

In the experiment itself, we examined the influencing role of three identifiable, possibly differing cue categories. The fact that these three categories did not show a significant influence on intentional forgetting does not mean that the experimental approach was free of other influencing cues. The best (and most extreme) way to control all retrieval cues between t1 and t4 would have been to tear down the laboratory and construct a totally new one for t4. In such a case, there would have been a high probability that every retrieval cue from t1 would have been excluded, and only those experimentally controlled and manipulated would have remained stable (Kluge & Gronau, 2018). This of course is the challenge that every real instance of change faces and it leads to the same limitations in implementation.

Regarding the methodological-related limitations, the present study was implemented in a special-purpose setting and used a random and rather small sample. It is possible that the study was limited in its generalization and external validity (Stone-Romero, 2011), as not all mundane aspects of a "real" organization and its characteristics could be replicated. On the other hand, field experiments come with other challenges and limitations, including a heterogeneous sample and threats to validity, such as maturity or other confounding variables that are difficult to control for. Special-purpose settings try to balance the aspects of internal and external validity.

Implications for Further Research. Since intentional forgetting is a process that is relevant not only to individual workers but also to teams and organizations (Kluge & Gronau, 2018), its extent needs to be taken into account in future research. Moreover, further research might investigate how other influences may explain what we understand as intentional forgetting. For example, it may be the case that factors such as complexity, difficulty, or easiness of the new actions to be performed as part of a changed routine hinder or help their learning. In this respect, participants may be unable to perform the new actions, and may perform nonprevailing actions, which would be considered an error in terms of intentional forgetting. Finally, individual dispositions may also influence the easiness (or otherwise) of behavioral adaptation to change. Research on these factors could contribute to a clearer understanding of intentional forgetting.

Practical Implications

It is nearly impossible to tear down a production plant and rebuild a totally new one in a different place in order to change the production process. Therefore, knowledge of the influences of different retrieval cues that can help shopfloor workers adapt to new routines and intentionally forget old ones is essential. Organizations that are confronted with change and new development processes can make use of these mechanisms in their change-management programs and interventions. Facing change does not simply mean creating and communicating a vision, training and enabling workers to behave according to the vision, and reinforcing and institutionalizing new routines, as is the case with many change-management concepts (e.g., based on Kotter, 1998, who addressed management practices, and Cummings & Worley, 2009, who addressed applied psychology). Training staff and implementing new routines are often not enough to ensure that these routines are applied successfully. Instead, documents, material, and technical equipment must be "cleaned" of cues that might encourage the recall of obsolete behavioral elements (Stegmaier, 2014). As theories on intentional forgetting suggest, knowledge and information about new routines, and willingness to execute them, are not enough to help workers and human operators change established behavior. This means that the identification and manipulation of retrieval cues that encourage intentional forgetting should become an additional aspect of change management.

Finally, our general set-up, in terms of the way in which behavioral change was measured, shows potential in the context of people analytics. People analytics represents the goal-directed use of data that are available through digitalization and new formats of data analysis to support decision-making in human resource management (Mühlbauer, Huff, & Süß, 2018), as, for example, in the context of change management. Our approach to exploring the difficulties in carrying out altered routines can help to tailor training in the workplace to the actions that are difficult to forget. Based on our method of data analysis, it is possible to identify the actions that are harder to forget, and to subsequently focus staff training and improve outcomes as a result.

In our study, we dealt with just one action-based change to certain elements of a production routine. Industry 4.0 and digitalization are drivers of mass customization, which is leading to individual and unique production processes in which no two procedures are identical or redundant. The emergence of Lot Size One means at least a little variance or modification in production processes. In relation to this challenge, we may contribute to a solution by proposing ways in which these challenges can be managed and production teams supported to cope with the increasing need for flexibility, individuality, change, and adaptation, by managing retrieval cues proactively.

Finally, although the present study primarily investigated production routines, intentional forgetting is needed for adaptation to any change, in fact for any change in human behavior, regardless of the situation, context, and background.

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