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Exploring the Discrepancy between Explicit and Implicit Keyboard Memory: The Role of Linguistic and Sensorimotor Context

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Abstract

Memory for the QWERTY keyboard has been shown to be a good experimental paradigm to test the relationship between explicit and implicit memory as, despite high typing proficiency in young students nowadays, explicit knowledge of the keyboard seems to remain scarce. In our experiment, we investigate the relationship between implicit and explicit keyboard memory by asking participants to find the 21 letters of the Italian alphabet on a blank QWERTY keyboard (explicit task) and then perform a procedural (implicit) task by typing short paragraphs. Results showed significantly lower explicit (compared to implicit) accuracy. To investigate the role of linguistic context in the implicit task, we compared these results with a subset from Experiment 1 in Ianì et al. (2024), who used a single letter procedural task, illustrating a decline in implicit performance between the two experiments. Our findings suggest the importance of linguistic and sensorimotor contextual factors for procedural knowledge.

Keywords: procedural knowledge; explicit knowledge; typing

Introduction

Explicit memory refers to knowing (semantic memory) and remembering (episodic memory) mental contents that are claimed to be memories (by describing them through words, drawings, or gestures). Procedural memory, on the other hand, refers to knowing how to do something (knowledge is revealed through actions; Breedlove, Watson & Rosenzweig, 2010). The two systems can function independently (e.g., Eichenbaum & Cohen, 2001), as evidenced by double dissociations (patients can show impairment in explicit memory but not in procedural memory, and vice versa, e.g., Klooser, Cook, Uc & Duff, 2015), and studies that show how humans can have very poor declarative memory of objects they see/interact with everyday such as the location of fire extinguishers (Castel, Nazarian & Blake, 2013) and the button layout of the elevator (Vendetti, Castel & Holyoak, 2013) of their workplace or details of very popular logos (Blake, Nazarin & Castel, 2015).

Independence between procedural and declarative information can be confirmed by cases where the two systems function in parallel without interfering with each other. At the same time, while being independent, in some circumstances the two systems can also affect each other, as evidenced, for instance, by studies in the field of Embodied Cognition (EC; e.g., Robinson & Thomas, 2021). A core idea underlying this approach, in the field of embodied memory, is that available procedural resources can be involved in the recovery of declarative mnemonic traces (Ianì, 2019). From a neuroscientific perspective, for instance, explicitly remembering self/other performed actions involves the activation of motor areas also at recall/recognition (Ianì, Burin, Salatino, Pia, Ricci & Bucciarelli, 2018; Masumoto, Yamaguchi, Sutani, Tsuneto, Fujita & Tonoike, 2006).

Thus, remembering a given event can also involve the reactivation of procedural and motor-related information that has also been activated during encoding. Crucially, such sensorimotor reactivation during retrieval is not an epiphenomenon, but a component of the memory traces through which our cognitive system can retrieve information. In this sense, motor and procedural information, albeit also potentially independent from declarative knowledge, can interact with the latter during encoding and retrieval in memory. Results consistent with this theoretical approach have come from a variety of research areas including eye movements, co-speech gestures, body posture, and bodily expression of emotion (Johansson & Johansson, 2014; Ianì et al., 2018; Limata, Bucciarelli, Schmidt, Tinti, Ras & Ianì, 2023; Wilkes, Kydd, Sagar & Broadbent, 2017). These studies have shown that the body (its position in space and its movements) can play a nontrivial role in the retrieval of a memory trace.

Memory for the QWERTY keyboard has been shown to be a very suitable experimental paradigm for testing the relationship between declarative memory (of the letters location) and the procedural (motor) use of the same information. The QWERTY keyboard is used daily and manipulated quickly, at least by young university students who prove to be proficient typists, performing about five strokes per second with a high degree of accuracy (e.g., Logan & Crump, 2011). In fact, Pinet, Zielinski, Alario &

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Longchamp (2022), have recently shown high typing expertise in a large cohort of university students, even without formal training. With this level of ability, one might expect that explicit knowledge of the letter position should also be extensive, and represent a crucial element influencing good typing performance. In fact, this is not the case. Previous studies have shown that even typing experts are often unaware of the details of the actions they usually perform or the details of the keyboard they use (e.g., Logan & Crump, 2009; Snyder, Ashitaka, Shimada, Ulrich & Logan, 2014), while their procedural knowledge, measured with typing performance, has been shown to be excellent (see also Liu, Crump & Logan, 2010). Scholars have explained this discrepancy with the so-called "two-loop theory" (Logan & Crump, 2011). According to this theory, key location information is encapsulated in the inner loop which translates the words into keystrokes and controls the movements of fingers. On the other hand, the outer loop connects language-related processes (i.e., comprehension) and provides the inner loop with a string of words to type, not necessarily having an explicit knowledge of how the inner loop assigns the letters to keystrokes by typing; thus, leading to a much poorer explicit than procedural memory of the QWERTY keyboard.

However, recently, Ianì, Stockner and Mazzoni (2024) have suggested that the two kinds of memory of the QWERTY keyboard are not completely independent but rather related. The authors confirm a significant positive correlation between explicit and implicit memory. Moreover, when applying a motor dual task (hands/arms tapping task), explicit keyboard memory decreased, suggesting that the motor task made procedural/motor resources less accessible which seem, to a certain extent, to support explicit memory. In other words, these findings suggest that the outer-loop was not able to access the inner loop for key localisation anymore. Interestingly, these findings are in contrast to Synder et al. (2014) who did not find a significant correlation between explicit/declarative and procedural keyboard memory, suggesting independence of the two memory systems. However, the methodology of the procedural typing task differed in an important way between the two studies: while Synder et al. (2014) asked participants to type texts, providing linguistic context, Ianì et al. (2024) asked participants to type single, individual letters, without providing linguistic context. In fact, it is also possible to observe a drop in performance between the typing task in Snyder et al. (2014) (accuracy = 93.6%) and the typing task in Ianì et al. (2024) (accuracy = 51%). However, typing-related cognition has considerably changed in the last decades (e.g., Pinet et al., 2022) which makes it difficult to directly compare these findings.

The present study aims to further investigate these convergent findings by comparing, in two samples of the current generation of typists, procedural/implicit and explicit keyboard memory. More specifically, while keeping the explicit task identical, in Experiment 1, we apply a procedural typing task, analogous to Snyder et al. (2014) but with an improved methodological design, that is having the letters on the keyboard not visible to participants. Then, we compared implicit performances at this task with those obtained with a single letter task (a subset of Experiment 1 in Ianì et al., 2024) in order to then carry out exploratory comparative analyses between the two experiments in order to test the role of the linguistic context in the implicit memory of the keyboard. The Bioethical Committee of Turin University approved the investigation.

Experiment 1

In Experiment 1 we tested explicit memory with an explicit cued-recall of QWERTY key positions. In addition, implicit memory was tested with an implicit procedural (i.e., typing) task, by typing two short paragraphs as in Snyder et al. (2014) but with masked letters. We hypothesize to replicate the previously discussed findings of Snyder et al. (2014); thus explicit memory accuracy (i.e., explicitly answering to the question "Where is letter __?") is expected to be significantly lower than the respective procedural memory accuracy (i.e., typing two brief paragraphs). Synder et al. (2014) confirmed this hypothesis but as letters on the keyboard were visible for the participants during the procedural task, the latter cannot be considered a pure implicit memory task.

Method

Participants

Since according to Logan and Crump (2011), most modern college students are skilled typists, we recruited typists from the Turin University, and also included people from the general population. We have tested 20 young adults (12 females, 8 males, mean age = 23.90, *SD* = 3.39).

Materials and Procedures

The explicit task was carried out on a 2-d keyboard printed on a blank sheet of paper. Typists were given a blank QWERTY keyboard printed on a 21 × 29.7 cm sheet of paper. For the explicit task the experimenter had the 21 letters of the Italian alphabet printed on a 3 x 3 cm sheet of paper (not visible to participants). The purpose was to avoid having the experimenter talk aloud and create differences in oral pronunciation for both letters and participants. The experimenter ran the function RANDOM () in the Excel software before the start of each experimental section and prepared the 3x3 sheets according to this randomization. Participants were instructed as follows: "now I will randomly show you a letter, and you should indicate where the letter is on the keyboard by saying out loud the number printed on the bottom of the key you think is the correct location". Each time a letter was shown, the experimenter repeated: "Where do you think this letter is located on the keyboard?". This section of the experiment lasted approximately 6 minutes. Typists never received any feedback on their accuracy. The probability of correct location was computed by assigning 1 or 0 to each correct or incorrect answer, respectively. Subsequently, each participant's mean of accuracy was calculated.

In a second phase, to obtain a procedural index of the QWERTY keyboard implicit knowledge, once the explicit task was concluded, typists completed a typing test with a real keyboard. The implicit typing task was the same procedural task as in Logan and Zbrodoff (1998) and Snyder et al. (2014), with different texts, but the same measure of accuracy. Participants were asked to type two texts that included all letters of the Italian alphabet and consisted of 111 and 124 characters, respectively. Subjects received the two texts one after the other. Order was randomized across participants. As in Logan and Zbrodoff (1998) and Snyder et al., (2014), while typing, the text remained on the screen but the typed letters were not echoed on the screen. We reiterate that, crucially, in contrast to both Logan and Zbrodoff (1998) and Snyder et al. (2014), during the typing test, keyboard keys were not visible in order to avoid that participants' responses relied on visual perception rather than procedural memory. According to the authors, this kind of task requires both implicit and explicit knowledge; however, being able to see the location of the letters, as in their study, might have reinforced explicit knowledge also through visual perception. Thus, we decided to try to replicate the effect by obscuring the letters on the keyboard. The computer measured the time from the first to the last keystroke, and speed was calculated as the number of words per time unit. Accuracy rates were scored by counting the number of typed words that contained errors. Speed and accuracy scores were both averaged over the two texts.

Results and Discussion

The probability that in the explicit task letters were correctly located on the keyboard was 0.46 (*SD* = .26), indicating that explicit knowledge was quite inaccurate and in line with the results obtained in Snyder et al. (2014) which observed an accuracy of 57.3 %. We observed the highest accuracy (95%) for the letter A and the lowest accuracy (20%) for the letter U. As illustrated in Figure 1, accuracy was instead very high in the typing (implicit) task (*M* = 0.83, *SD* = .16), in line with the results (93.6%) obtained in Snyder et al. (2014).

Accuracy in the explicit task was significantly lower than accuracy in the typing task, $t(19) = -7.27, p < .001$, which involved a mixture of implicit and explicit knowledge. It is crucial that, differently from Snyder et al (2014), this result was obtained when only memory for letter location on the keyboard was available, as letters were obscured, thus without any help of visual information. In order to further investigate the high error rate in the explicit task, we carried out an error-type analysis following the methodology of Ianì et al. (2024), based on Gertner, Grudin, Larochelle, Norman & Rumelhart (1983). More specifically, errors were coded into three distinct categories: I. "Neighbour/Same row" (a key in close proximity to the target key on the same row), II. "Neighbour/Different row" (a key adjacent to the target key but on a different row) and III. "Distant" (any other answers). A χ^2 test revealed a significant difference in error frequencies between categories ($\chi^2(2) = 62.16$, $p < .001$): most errors (*N* = 114) belonged to category III, followed by category I (*N* = 90) and finally, category II (*N* = 21). This indicates that erroneous answers were in most cases distant to the target key, further suggesting the lack of explicit knowledge of the keyboard. Additionally, we also verified that the paragraphs used in the implicit task did not contain more letters that were easy (=higher accuracy) in the explicit task. In order to test this, we assigned to each character of the texts to be typed (implicit task) the mean accuracy rate of the corresponding letter encountered in the explicit task as an index of letter "difficulty". We then computed the overall difficulty mean for all characters (*N* = 235) of the typing task (M = .50) which did not significantly differ from the accuracy mean of the 21 letters in the explicit task (M = .46) (t(24.683) = -0.91, *p* = .37). In order to strengthen these results, we further ran a Bayesian independent samples t-test using the same data structure, obtaining a BF_{01} of 3.16 for the difference between the two tasks. This result provides more support for the null hypothesis compared to the alternative hypothesis (see, Jarosz & Wiley, 2014).

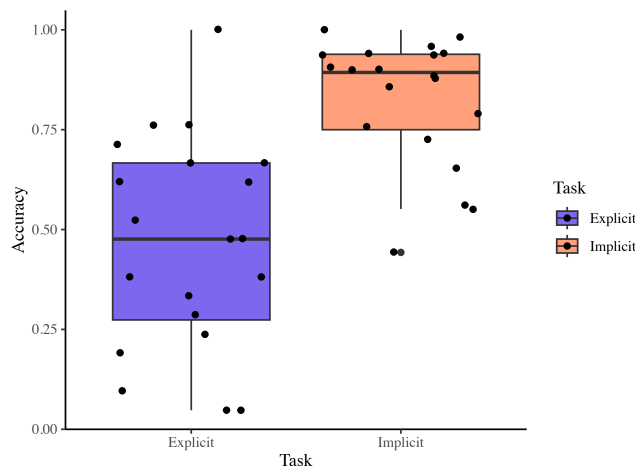

Figure 1: Accuracy in the explicit and implicit task of Experiment 1

These results suggest that the skilled typists' explicit knowledge of the key locations is insufficient to support performance in the typing test. Their incomplete explicit knowledge must have been supplemented by excellent implicit knowledge to produce high typing accuracy. Typing speed was 24.89 WPM, words per minute (*SD* = 10.56). Even if a correlation needs to be taken with great caution, just as a suggestion of the trend of the data, we report that typing speed correlated positively with accuracy in the typing task ($r(18) = .66, p < .01$), but not with performance on the explicit task ($r(18) = .18, p = .45$). Finally, typists' accuracy in the typing test was significantly related to their performance in the explicit task ($r(18) =.55, p < .05$).

These data confirm that people can have poor explicit knowledge of a very familiar object such as the QWERTY keyboard. As mentioned above, literature has shown that people are usually also unable to recall the feature of coins they manipulate every day, the locations of fire extinguishers (e.g., Castel et al., 2013) or button layouts of the elevator in the space they work every day (Vendetti et al., 2013) etc. However, in these examples, humans do not have to remember, for instance, the particular symbol on a coin in order to correctly use it in everyday situations, whereas, in order to correctly type, people need to know exactly where the keys are. Our findings confirm that this type of knowledge is primarily procedural and rather inaccessible to explicit systems. However, interestingly we found a significant correlation between explicit and procedural keyboard knowledge. While this is in contrast with Snyder et al. (2014), who found the two types of memory not to be related with each other, it is in line with Ianì et al. (2024) who found evidence that explicit and procedural keyboard knowledge might interact. Both in the current experiment and in Ianì et al. (2024), pure implicit knowledge (by obscuring the keyboard) was measured. This suggests that, when ruling out the possible role of the perceptual system in the typing task, procedural and explicit knowledge are related.

Comparative Analysis with Exp1 in Ianì et al. (2024)

Here we present a subset of Experiment 1 in Ianì et al. (2024) where a modified version of the procedural task was used: instead of writing sentences, participants were asked to type each letter of the alphabet one at a time and without seeing the letters' location on the keyboard. This new procedural task directly corresponds to the explicit task by assessing procedural knowledge letter by letter. New analyses were run on a subset of the data in order to carry out exploratory comparative analysis between the two different typing tasks.

Method

Participants

The data from 20 young adults of the dataset by Ianì et al. (2024) were selected, matched by gender and age with the participants from Experiment 1 (12 females, 8 males, mean age = 23.95 years, *SD* = 3.27).

Materials and Procedure

The material and procedure of the explicit task in Exp 1 of Ianì et al. (2024) were the same as in our Experiment 1. Only the typing task changed: in Ianì et al. (2024), participants sat in front of a computer and were presented with the 21 letters of the Italian alphabet in random order using E-prime (version 3.0). Each letter was followed by a black screen of 2000 ms and a fixation cross of 500 ms announcing the appearance of a new letter. The authors asked the participants to press the key on the keyboard where they thought the letter was located. Immediately after the participant's response, they proceeded to the next trial (next letter). Accuracy as well as reaction times (RT; time from stimulus onset to the pressed key in ms) were measured.

Results and Discussion

Exploratory cross-experimental analyses between our Experiment 1 (paragraph typing task: mean accuracy = 83%) and the subset of Ianì et al. (2024) (single letter typing task: mean accuracy = 55%) showed a significantly lower accuracy in the (single) letter version ($t(29.53) = 3.77$, $p < .001$), see Figure 2. Explicit accuracy did not differ between the two samples: $t(36.198) = .44$, $p = .66$.

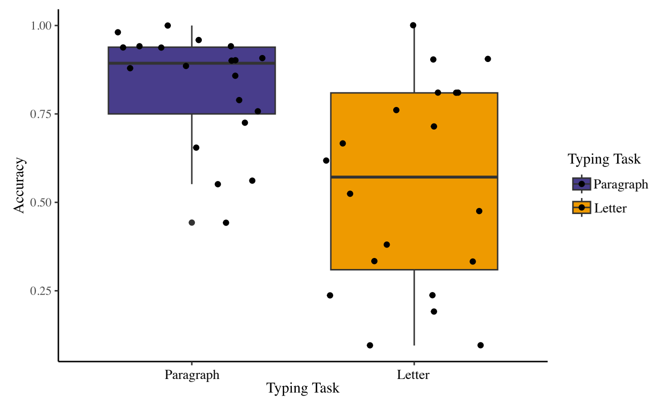

Figure 2: Accuracy in the paragraph typing task (Exp 1) and the (single) letter typing task (subset Exp1 from Ianì et al., 2024)

To rule out that the texts used in the implicit task of Experiment 1 did not contain more letters that were easier to type compared to the single letter version of Ianì et al. (2024), we further performed the same difficulty analysis as in Experiment 1. This time we assigned to each letter of the texts the mean accuracy encountered for each letter in the implicit task of Ianì et al. (2024). A two sample t-test showed the overall "difficulty" means of the tasks (implicit task Ianì et al. (2024): $M = .55$, implicit task Exp1: $M = .61$) to significantly differ ($t(254) = 2.33$, $p < .05$).

In order to make sure the encountered results were not driven by the selection of the matched participants from Ianì et al. (2024), additional comparative analyses with the complete sample of Ianì et al. (2014) (N = 48) were carried out. The analyses produced comparable results with the only difference of the letter difficulty between the two different implicit tasks not being significant ($t(254) = 1.20$, $p = .23$). A Bayesian independent samples t-test strengthened these results by obtaining a BF_{01} of 2.29 for the difference between the two tasks, thereby suggesting that the differences between the two tasks are due to the two forms of memory traces and not to the difficulty of the tasks.

General discussion

In Experiment 1 we investigated the explicit vs. procedural memory of the QWERTY keyboard and subsequently, the relationship between two different tasks assessing the procedural knowledge through exploratory comparison of implicit performance in a typing task of texts (Experiment 1 here) with a typing task of single letters (Experiment 1 in Ianì et al., 2024). Our preliminary results suggest a significantly higher accuracy in the implicit (vs. explicit) task, confirming previous studies on the discrepancy between implicit vs.

explicit QWERTY memory performance (e.g., Ianì et al., 2024; Liu et al., 2010; Snyder et al., 2014).

Further investigating the mechanisms underlying the procedural typing tasks, we found accuracy in Experiment 1 of Ianì et al. (2024) (single letter typing task) to be significantly lower than in a typing task consisting of whole paragraphs. This preliminary finding confirms the facilitating role of the linguistic context for implicit memory of the QWERTY keyboard. As Ianì et al. (2024) argued, it is likely that previously typed letters play a triggering role for the letters to be subsequently typed. This finding can be explained by chunking processes that enable parallel processing of component actions reducing the cognitive load and leading to skilled performances (e.g., Rosenbloom, Laird & Newell 1989). Yamaguchi and Logan (2014) have shown that chunking in typing can occur both on a perceptual linguistic level (word processing) as well as on a motor planning level (key-letter association that allows typing without the explicit knowledge of the keyboard). This is in line with the hierarchical theories of typing (i.e. the two-loop theory discussed above), illustrating how letters and keystrokes are not processed as single units but rather as chunks; thus, the outer-loop, associated with higher-order cognitive and linguistic processes, operates at word or even sentence-levels (e.g., Logan & Crump, 2011). Evidence in this regard stems from studies that show how typing rates decrease when the order of letters in words are scrambled, preventing the application of chunks during typing (e.g., Yamaguchi & Logan, 2014). We expect the same phenomena to have occurred in the typing task requiring single letter typing. This facilitating effect of "chunking" has not only been shown in typing but also in other contexts, such as piano learning. Pianists typically tend to learn by creating interconnected chunks of keystrokes, with each chunk functioning as a sort of cue for the next, so that playing one section is a trigger for the next (Lehmann, Sloboda & Woody, 2007). Our results are also consistent with a study by Lisboa, Chaffin and Begosh (2010), who reported a case study with a pianist who was tested with both played recall (motor production task) and written recall (verbal report task) after learning a passage. The results showed that the played recall was better than the written recall. According to the authors, these results are due fewer sensorimotor cues about what comes next provided by the written recall condition. Our results, thus, not only support the facilitating role of linguistic context for the specific typing action and procedural keyboard memory but also, more generally, suggest the role of chunking in cognitive functioning serving as facilitating linguistic and sensorimotor cues. In this line, it would be interesting to investigate whether similar linguistic or sensorimotor cues (allowing chunking) would also be beneficial for explicit memory performance.

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