

## Suppressing visual feedback in written composition: Effects on processing demands and coordination of the writing processes

Thierry Olive

*CNRS - LaCo and University of Poitiers, France*

Annie Piolat

*University of Provence, Aix-en-Provence, France*

The goal of this experiment was to investigate the role of visual feedback during written composition. Effects of suppression of visual feedback were analyzed both on processing demands and on on-line coordination of low-level execution processes and of high-level conceptual and linguistic processes. Writers composed a text and copied it either with or without visual feedback. Processing demands of the writing processes were evaluated with reaction times to secondary auditory probes, which were analyzed according to whether participants were handwriting (in a composing and a copying task) or engaged in high-level processes (when pausing in a composing task). Suppression of visual feedback increased reaction time interference (secondary reaction time minus baseline reaction time) during handwriting in the copying task and not during pauses in the composing task. This suggests that suppression of visual feedback only affected processing demands of execution processes and not those of high-level conceptual and linguistic processes. This is confirmed by analysis of the quality of the texts produced by participants, which were little, if at all, affected by the suppression of visual feedback. Results also indicate that the increase in processing demands of execution related to suppression of visual feedback affected on-line coordination of the writing processes. Indeed, when visual feedback was suppressed, reaction time interferences associated with handwriting were not reliably different in the copying task or the composing task but were significantly different when visual feedback was not suppressed: They were lower in the copying task than in the composition task. When visual feedback was suppressed, writers activated step-by-step execution processes and high-level writing processes, whereas they concurrently activated these writing processes when composing with visual feedback.

Lors de la production d'un texte, l'effet de la suppression du feedback visuel sur le coût et la coordination des processus rédactionnels d'exécution graphique et de haut niveau (planification conceptuelle et linguistique, contrôle) a été étudié. À cette fin, avec ou sans feedback visuel, les participants ont produit un texte puis l'ont copié. Le coût attentionnel des processus rédactionnels a été évalué à l'aide d'une tâche secondaire de temps de réaction (TR). Chaque TR a été catégorisé en fonction de l'activité du rédacteur: transcription (en copie et en production de texte) ou lors des pauses durant la production de texte. Les principaux résultats montrent que, durant la copie, la suppression du feedback visuel s'accompagne d'une augmentation du TR moyen associé à la transcription alors que, pendant la production du texte, le TR moyen associé aux pauses n'augmente pas. Ceci suggère que la suppression du feedback visuel affecte le coût des processus d'exécution et non pas celui des processus rédactionnels de haut niveau. Cette interprétation est confirmée par l'analyse de la qualité des textes produits par les participants qui montre que ces derniers n'ont pas été influencés par la suppression du feedback visuel. Les résultats indiquent également que la suppression du feedback visuel affecte la coordination des processus rédactionnels. En effet, quand le feedback visuel est supprimé le

Requests for reprints should be addressed to Thierry Olive, LaCo CNRS MSHS  
99 av. R. Pineau, F- 86022 Poitiers, France (E-mail: [thierry.olive@univ-poitiers.fr](mailto:thierry.olive@univ-poitiers.fr)).

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coût de la transcription n'est pas différent en copie et en production de texte alors qu'il est significativement différent lorsque le feedback n'est pas supprimé. Dans ce dernier cas, le coût associé à la transcription est inférieur durant la copie par rapport à la production de texte. Sans feedback visuel, les rédacteurs activent pas à pas les processus d'exécution et de haut niveau, alors qu'en situation habituelle, ils les activent simultanément.

El objetivo de este experimento fue investigar el papel que desempeña la retroinformación visual durante la composición escrita. Se analizaron los efectos de la supresión de la retroinformación visual tanto en las demandas de procesamiento como en la coordinación en línea de los procesos de baja ejecución y de los procesos conceptuales de alto nivel y lingüísticos. Los participantes compusieron un texto y lo copiaron, ya fuera con o sin retroinformación visual. Se evaluaron las demandas de procesamiento de los procesos de escritura mediante tiempos de reacción a sondeos auditivos secundarios que se analizaron dependiendo de que los participantes estuviesen escribiendo (en una tarea de composición o de copia) o dedicados a procesos de alto nivel (cuando hacían pausas durante la tarea de composición). La supresión de la retroinformación visual aumentó la interferencia a los tiempos de reacción (tiempo de reacción secundario menos línea base del tiempo de reacción) durante la escritura en la tarea de copia y no durante las pausas durante la tarea de composición. Esto sugiere que la supresión de la retroinformación visual afectó solamente las demandas de procesamiento de los procesos de ejecución y no de los conceptuales de alto nivel y lingüísticos. Esto se confirma por medio del análisis de la calidad de los textos producidos por los participantes, a los cuales afectó poco, si es que los afectó del todo, la supresión de la retroinformación visual. Los resultados también indican que el aumento de las demandas de procesamiento de la ejecución, relacionadas con la supresión de la retroinformación visual, afectó la coordinación en línea de los procesos de escritura. En efecto, cuando se suprimió la retroinformación visual, las interferencias asociadas a la transcripción no fueron diferentes en copia y en producción de texto, aunque sí difirieron significativamente cuando la retroinformación no se suprimió. En este último caso, el esfuerzo asociado a la transcripción fue inferior durante la copia en comparación con la composición de texto. Sin retroinformación visual, los escritores activaron paso a paso los procesos de ejecución y los de alto nivel, en tanto que con retroinformación visual, los activaron simultáneamente.

### PROCESSING DEMANDS OF THE WRITING PROCESSES WITH SUPPRESSION OF VISUAL FEEDBACK

Since the works of Hayes and Flower (1980), writing has been considered as an activity engaging high-level cognitive operations concerned with the retrieval and organization of information and with the formulation of ideas in language. Most of the studies that followed this concept have focused on the structure of the writing processes or studied the relationship between writing processes and long-term working memory. In parallel, low-level processes of handwriting were investigated from a psychomotor perspective and detailed models of handwriting have been proposed (i.e., Ellis, 1988; Van Galen, 1991). Because research on the impact of working memory on writing processes has recently increased (Kellogg, 1996), it is now possible to investigate processing demands of high-level writing processes and of execution processes and their impact on the on-line management of the writing processes.

Following Kellogg (1994) and Levy and Ransdell (1995), high-level writing processes are concerned with *formulation* of language. The process of planning concerns retrieval of information in long-term memory,

organization of the content of the discourse, and goal settings. The process of translating concerns transformation of the products of planning into sentences. Text *monitoring* requires a critical reading of the text and a detection of errors or problems. Low-level processes refer to the *execution* of word characters (programming and executing sequences of movements). Both low- and high-level processes exploit the text already written. For example, the written trace allows writers to monitor their text by re-reading and to control their handwriting by adjusting their movements. Furthermore, both low- and high-level writing processes demand resources from working memory. Formulation and monitoring are effortful processes (Grabowski, 1999; Kellogg, 1999) and execution, which is automatized in adults, demands resources in children (Kellogg, 1999; McCutchen, 1996). In text composition studies, the analysis of processing demands of the high-level writing processes generally involves two kinds of variables: fluency (Levy & Ransdell, 1996; McCutchen, 1996) and reaction times to secondary probes (Olive, Kellogg, & Piolat, 2001; Piolat & Olive, 2000). In this context, the aim of the present research is to investigate the role of visual feedback on processing demands of low- and high-level writing processes. For this purpose, a secondary probe task was used to analyse processing demands of the low- and high-level writing processes when visual feedback was or was not suppressed.

The relationship between working memory resources and processing visual feedback during handwriting has been investigated mainly by comparing writers composing under normal visual feedback conditions with writers composing in the absence of visual feedback (for example, by asking participants to use a pen without ink). Studies conducted in this context have shown that the suppression of visual feedback generally increases the processing demands of writing (Grabowski, 1999; Graham & Weintraub, 1996; Van Doorn & Keuss, 1992, 1993; Van Galen, Smyth, Meulenbroek, & Hylkema, 1989; Zesiger, 1995). However, two accounts of how visual feedback affects the processing demands of writing can be distinguished in the literature according to the kind of process that is presumed to be affected.

According to the first account, visual feedback is used to erase motor programmes already executed from working memory and thus it decreases the processing demands of motor transcription (Graham & Weintraub, 1996; Zesiger, 1995). Empirical arguments supporting this assumption come from studies that primarily focused on the motor processes of handwriting. For example, Zesiger observed, in children learning to write, that the quality of handwriting decreased progressively with increasingly degraded visual feedback. The same phenomenon was observed in adult writers using an inkless pen. This resulted in less accurate letter formation (omitting or adding features) and incorrect text alignment (Smyth & Silvers, 1987; Van Galen et al., 1989; Van Doorn & Keuss, 1992, 1993). Ellis, Young, and Flude (1987) observed that dysgraphic patients showed the same symptoms (in terms of handwriting errors) as "normal" writers who were prevented from using visual and tactile-kinaesthetic feedback.

According to the second account, visual feedback of the writing trace facilitates operations of the high-level writing processes. This account has been supported by researchers who primarily investigated text composition or who were interested in comparing the speaking and writing modalities of language production. In contrast to writing with an inkless pen or to speaking, the text produced in normal handwriting acts as an "external store" that does not need to be memorized entirely by the writer. Thus, writers in standard writing conditions can exploit the text already written, handle larger units of discourse, and better revise their production for the better. Hull and Smith (1983) claimed that re-reading could be considered as a behavioural characteristic of "good" writers because they reflect on their text more often than novice writers do. Grabowski (1999) assumed that the permanence of the written trace might also explain the superiority of writing as compared to speaking, in terms of the syntactical and semantic quality of the written text (see also Chafe, 1982). Therefore, visual feedback can also reduce the processing demands of the high-level writing processes.

Studies that analyzed effects of the suppression of visual feedback on text quality provided convergent data with this interpretation. Usually, when writers are prevented from using visual feedback, the quality of their text is lower than when writers compose with visual feedback.

For instance, suppression of visual feedback influenced syntactic structure (Piolat, 1982), coherence (Atwell, 1981; Hull & Smith, 1983), number of separate ideas expressed in the text (Galbraith & Sumpner, 1996), writers' productivity and fluency (Dansac & Passerault, 1996), and general quality of texts in adults (Hull & Smith, 1983) as well as in children (Flamen & Piolat, 1999). However, such findings have not been systematically observed. For instance, the suppression of visual feedback did not affect the written recall of short fables (Teleman, 1981) or the composition of a business letter (Gould, 1980). One reason these two authors may have failed to find any effect of the suppression of visual feedback may be linked to the tasks used in their experiments. As Brown, McDonald, Brown, and Carr (1988) noted, a written recall task does not rely on operations of formulation but only on generating output of formulation. Moreover, as noted by Hull and Smith (1983), in Gould's experiment, it is likely that writing a business letter induced the use of a well-practised script that did not interact with any execution process.

In sum, there is general agreement in the literature concerning the beneficial effect of visual feedback in handwriting. The written trace allows writers to control their production and to erase already-executed motor programmes from working memory. Furthermore, it might facilitate the operation of high-level writing processes by providing the writer with permanent access to what has already been written. Accordingly, the first goal in conducting the present experiment was to confront the two accounts mentioned earlier. We sought to determine whether suppression of visual feedback affects processing demands of low-level processes (execution) or of high-level processes (formulation and monitoring).

The second goal of this experiment was to analyze how changes in the processing demands of the writing processes affect their on-line coordination. Kellogg (1996) has argued that although written composition is a highly demanding cognitive activity, multiple processes can be activated concurrently as long as adequate resources are available. Further, Fayol (1999) proposed that automatization of the writing processes is an essential mechanism that, because it provides supplementary resources, allows the simultaneous coordination of several writing processes. Olive and Kellogg (in press) reported results supporting the claims of these two authors. First, they showed that adults composing in standard writing conditions (i.e., with visual feedback) are able to activate the high-level writing processes simultaneously to execution. Second, they provided evidence that automatization of the writing processes, and more precisely of the execution processes, mainly affects the simultaneous activation of the high- and low-level writing processes. The level of automaticity of the execution processes was manipulated by comparing adults composing with visual feedback with either children producing handwriting in the same conditions or with adults producing handwriting with an unpractised calligraphy. In adults, Olive and Kellogg (in press), by contrast, observed an automatization of the low- and high-level writing processes in children and an increase in the

processing demands of execution processes in adults writing with an unpractised mode of transcription. Further, they reported that in children and in adults handwriting with an unfamiliar calligraphy activated the low- and high-level writing processes step-by-step. They explained these findings by arguing that in children and in adults using an unfamiliar calligraphy, execution processes engage many resources, which does not allow the concurrent activation of high-level writing processes.

One other interesting finding about the on-line coordination of the writing processes was reported by Olive (1999), using the same method as Olive and Kellogg (in press). Olive investigated the on-line coordination of the low- and high-level writing processes when an unusually large amount of resources was devoted to the high-level writing processes. In order to increase the amount of resources engaged by these high-level processes, Olive asked writers to compose the best text they had ever composed (by means of instructions that stressed both conceptual organization and linguistic formulation of the text). By contrast with writers composing in standard conditions, this manipulation increased resources devoted to high-level writing processes but did not affect their coordination with the low-level execution processes. This latter finding was explained in terms of a strategic concurrent coordination of the several high-level writing processes. When execution is automatized, sufficient resources are available for activating both execution and high-level writing processes. However, when the high-level writing processes engage supplementary resources, because they are composed of several writing subprocesses, writers can skip between these subprocesses and activate the less demanding ones in order to stay within the limits of the cognitive capacity. Thus, following the Olive and Kellogg (in press) and Olive (1999) experiments, suppression of visual feedback should affect the on-line coordination of the writing processes only if composing without visual feedback increases the processing demands of the low-level execution processes.

In the present experiment, the same method as that designed by Olive and Kellogg (in press) was used. More precisely, in order to separate the low- and high-level writing processes, to analyze their respective demands in cognitive resources and to analyze whether writers concurrently activate these writing processes, participants performed two different primary tasks - text composition and text copying - in dual-task conditions. The rationale for designing this method is as follows. Dual-task experiments are generally used to analyze processing demands of cognitive activities. This paradigm is based on the assumption that the two tasks share a common and limited pool of resources, and that when performed simultaneously, the increase in interference between the two tasks indicates their processing demands. In the secondary task used in the present experiment, participants were required to rapidly detect auditory probes during text composition and during the copying task. Processing demands were measured in terms of probe reaction time (RT) interference, for instance, when mean baseline RTs to detect auditory

probes in simple task condition were subtracted from the RTs obtained in the dual-task condition. The greater the interference in RT, the more processing demands required at the moment of the probe (Kahneman, 1973; Kerr, 1973) |.

The key point in designing the method was to separate clearly the high- and low-level writing processes (i.e., separating formulation and monitoring processes from execution processes) and to associate RT interferences with these writing processes. Whereas in text composition the high- and low-level writing processes are both activated, in the copying task only low-level writing processes are activated (high-level writing processes are little, if at all, activated). However, comparing RT interference associated with these two primary tasks only informs on the demands of text composition or of the copying task. A finer-grained analysis of these two tasks is necessary. Indeed, when copying a text, participants can read the original text and neither low-level nor high-level writing processes are activated. However, when they transcribe their text, only execution processes are activated. Consequently, RT interference associated with handwriting during the copying task informed on the processing demands of the execution processes. Furthermore, when composing a text, participants can activate both low- and high-level writing processes (see Figure 1) but, when they are pausing, only high-level writing processes are activated (although they can also think of something not related to the task, e.g., daydreaming). Consequently, RT interference associated with pauses during the composition task informed on the processing demands of high-level writing processes.

By distinguishing these two different writers' activities (handwriting-copying, pausing-composing) and by comparing a situation in which writers composed with or without visual feedback, it was possible to analyze the effect of the suppression of visual feedback on processing demands of execution processes and of the high-level writing processes (formulation and monitoring). Accordingly, if visual feedback decreases processing demands of execution processes, then we predict that RT interference associated with handwriting during the copying of the text should be higher when visual feedback is suppressed than when it is provided to writers. By contrast, if visual feedback decreases the processing demands of high-level processes, then we predict that RT interference measured during pauses in text composition should be higher when visual feedback is suppressed as compared to a situation where writers can use it.

Finally, concurrent activation of the low- and high-level writing processes was investigated by comparing RT interference associated with handwriting during the composition task and during the copying task (Olive & Kellogg, in press). Indeed, when handwriting during text composition,

| Several studies that investigated whether a secondary auditory probes task affects writing performance have shown that it is not the case (Piolat, Olive, Roussey, Thunin, & Ziegler, 1999; Piolat, Roussey, Olive & Farioli, 1996).

		Writer's activity	
		Handwriting	Pausing
Task	Copying	Execution	No writing process
	Composing	Execution*or Execution + High-level writing processes**	High-level writing processes

\* When the low- and high-level writing processes are coordinated step-by-step.

\*\* When the low- and high-level writing processes are coordinated concurrently.

**Figure 1.** Low- (execution) and high-level writing processes (formulation and monitoring) involved in a copying and composing task according to whether writers are handwriting or pausing (writers' activity was considered as handwriting when the pen was on the tablet, or when it was off the tablet for less than 250 ms; and as pausing when the pen was off the tablet for more than 250 ms).

execution is activated, but presumably, high-level writing processes may occur in parallel to the extent that sufficient processing resources are available (see Figure 1). Therefore, if writers concurrently activate the low- and high-level writing processes, RT interference associated with handwriting during the composition task should be higher than RT interference associated with handwriting during the copying task, where only execution processes are activated.

In sum, the present study analyzed RT interference associated with (1) transcription during a copy (handwriting-copying), (2) pauses during a text composition (pausing-composing), and (3) transcription during a composition (handwriting-composing). These three RT interference conditions were compared in participants who were used their visual feedback ("feedback" condition) or who wrote with an inkless pen ("no feedback" condition). Furthermore, we also examined (1) writers' productivity by analyzing the volume of the texts and writing fluency measured as the number of words produced per minute, and (2) quality of the texts composed in terms of quality judgements, syntactic complexity, mechanical errors, and revisions. This was done to obtain further evidence about the effect of the suppression of visual feedback. Indeed, if, with visual feedback, writers can exploit the written trace of the text already written to handle larger units of discourse and to revise their text better, the suppression of the visual feedback should result in poorer text. It was thus expected that if composing a text without visual feedback affects the high-level writing processes, text quality should be lower than when composing in the standard condition.

## EXPERIMENT

### Method

**Participants.** Forty undergraduate students of psychology (mean age: 21.3 years; 27 females, 13 males) of the University of Provence participated in this experiment. Participants were randomly assigned to the two

experimental groups (20 participants in the "feedback" condition, and 20 others in the "no feedback" condition).

**Material and apparatus.** Participants composed their text and copied on an A4 Wacom digitizer tablet connected to an Apple LC computer with an electronic pen. A computer program in Hypertalk™ language controlled the secondary reaction time task and categorized each reaction time with respect to the writer's activity (i.e., handwriting or pausing in the composing and copying tasks). More precisely, when the electronic pen was on or off the tablet for less than 250 ms participants were presumed to be primarily involved in handwriting and RTs were categorized as execution processes. Pauses below this threshold were also considered as reflecting low-level operations because they correspond, for example, to the transcription of a dot on the "i." Above this threshold, pauses were considered as time devoted to high-level writing processes, such as planning, translating, or reviewing, and RTs were categorized as high-level writing processes. The program did not record pen movements or length of pauses. Only length of RTs and writer's activity at the moment of the probe were recorded.

Writers were sited in the front of the digitized tablet. In all phases of the experiment where probes were distributed, participants were asked to respond to the probes by pressing the spacebar of a computer keyboard with their nondominant hand. The keyboard was installed behind the digitizer tablet but shifted at left or right according to the writers' nondominant hand. Thus, the keyboard's spacebar was easily accessible by each participant.

In the feedback writing condition, participants composed their text and copied it onto blank sheets with an electronic pen with ink. In the no feedback writing condition, participants composed their text and copied it with an electronic pen without ink. They were provided special sheets consisting of a carbon paper inserted between two blank sheets (the visible sheet was lined). Thus, writers were not able to see what they were writing but the experimenter was able to collect the texts that participants produced. In the two conditions, during the copying task, the text participants had to copy was positioned against a vertical panel in front of them, just behind the keyboard.

**Procedure.** First, general instructions concerning the experiment were provided to the participants. Then, in order to compute their mean baseline RTs, participants performed a simple reaction time task. Thirty auditory probes were randomly distributed in an interval with a mean of 10 s and a range of 5 s to 15 s. Participants were asked to react as rapidly as possible whenever they detected a probe. The mean baseline RT of each participant was calculated from the 25 last RTs (the first 5 trials were treated as warming-up trials).

In the second phase of the experiment, the secondary reaction time task was introduced. Participants were informed that during text composition they would occasionally hear auditory probes. They were again asked to react as rapidly as possible to the probes. During the

composition task, probes were distributed randomly in an interval with a mean of 30 s and a range of 15 s to 45 s<sup>2</sup>. Participants composed a persuasive text on the following topic:

The universities need more finance to renew their buildings and to buy new computers and teaching material. What do you think about an increase of the university tuition fees to cover these expenses? Can you write pro and con arguments concerning this planned increase of the students' tuition fees?

Participants were informed that they could modify their text by adding, deleting, or rewriting words or sentences. They were told to take as much time as they needed to write their text. They were reminded to concentrate fully on their text but to respond as rapidly as possible to the auditory signals. When they finished, participants had to press a special key on the keyboard to stop the secondary reaction time task.

In the next phase of the experiment, participants copied their text (with a digitizer tablet) while again submitting to the secondary reaction time task. To improve the memory accessibility of the written text, participants read it twice before copying it. Participants were informed that they would continue to hear signals occasionally during the copy task and that they had to continue to respond to them as rapidly as possible by pressing the spacebar of the keyboard with their nondominant hand. The experimenter asked the participants to copy their text as it was in the original composition. More precisely, they were asked to be unaware of errors they could detect in the original copy and also of errors they might introduce to the copy. Moreover, participants were asked to copy the text in their usual handwriting style. There was no time limit to perform the copy task.

## Results

### RT interference

A preliminary analysis showed that the baseline RT for participants in the feedback condition ( $M = 550$  ms) and for participants in the no feedback condition ( $M = 543$  ms) was statistically equivalent,  $t(38) = 0.463, p > .05$ . For each participant, RT interference scores were calculated for each of the three following writers' activities: handwriting-copying, pausing-composing, and handwriting-composing.

A 2 (Feedback condition: feedback, no feedback)  $\times$  3 (Activity: handwriting-copying, pausing-composing, handwriting-composing) analysis of variance was conducted with repeated measures on the last factor. The feedback

<sup>2</sup> Participants responded to 12.5 probes on average in the feedback condition and to 17.5 probes on average in the no feedback condition. This is due to difference in time spent on the tasks. For instance, the copying and composing task were longer in the no feedback condition than in the feedback condition.

( $M = 196$  ms) and no feedback ( $M = 187$  ms) conditions were not significantly different,  $F(1,38) = 0.127, p > .05$ . A main effect of the Activity factor was observed,  $F(2,76) = 9.51, p < .001$ . The Feedback condition  $\times$  Activity interaction was significant,  $F(2,76) = 12.03, p < .0001$ . The mean RT interferences are plotted in Figure 2.

To analyze the effect of suppressing the visual feedback processing demands of the high- and low-level writing processes, post hoc comparisons (Sheffé test) were conducted on each RT interference. Reaction time interference associated with handwriting-copying was significantly shorter in the feedback condition than in the no feedback condition (134 ms and 184 ms, respectively,  $p < .05$ ). RT interference associated with pauses during text composition was not significantly different in the two feedback conditions (feedback = 185 ms; no feedback = 200 ms). RT interference associated with handwriting during the text composition task was significantly longer in the feedback writing condition than in the no feedback writing condition (268 ms and 178 ms, respectively,  $p < .01$ ).

The coordination of the low- and high-level writing processes was analyzed by conducting two separate analyses of variance with repeated measures on the three RT interferences (handwriting-copying, pausing-composing, handwriting-composing) for the feedback and no feedback conditions. In the feedback condition, RT interferences were significantly different,  $F(2,38) = 19.8, p < .0001$ . The mean RT interference associated to handwriting was significantly shorter in the copying task ( $M = 134$  ms) than in the composing task:  $M = 268$  ms,  $F(1,38) = 38.88, p < .0001$ , and than when associated with pauses during the composition task:  $M = 185$  ms,  $F(1,38) = 5.66, p < .05$ ; the two latter RT interferences being significantly different,  $F(1,38) = 14.86, p < .001$ . In the no feedback condition, the RT interferences for handwriting-copying ( $M = 184$  ms), pausing-composing ( $M = 200$  ms), and handwriting-composing ( $M = 178$  ms) were not significantly different.

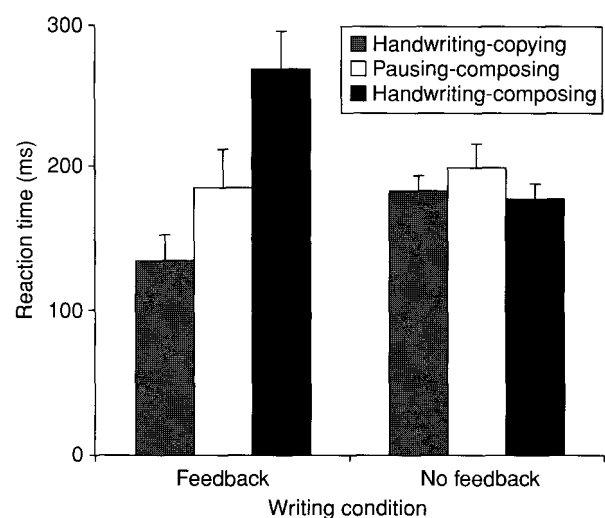


Figure 2. Mean secondary reaction times (in ms) and standard errors for the feedback and no feedback writing conditions.

Writing performance

Volume. An effect of feedback condition was observed on the total number of words produced during text composition,  $t(38) = 2.249, p < .05$ . In the feedback condition, participants produced fewer words ( $M = 199$ ) than in the no feedback condition ( $M = 263$ , see Table 1).

Writing fluency. Fluency was calculated by dividing the total composition time by the total number of words produced during text composition (including crossed-out words). The mean numbers of words per minute (wpm) were entered in a 2 (Feedback condition: feedback, no feedback)  $\times$  2 (Task: copying, composing) analysis of variance with repeated measures on the last factor. The number of wpm was not significantly affected by the feedback condition. Across the two tasks, participants produced 17.7 wpm with visual feedback and 17.2 wpm without visual feedback. The task significantly affected the number of wpm,  $F(1,38) = 117.42, p < .0001$ . During the copying task, participants wrote 20.8 wpm whereas they wrote 14.2 wpm during text composition. The Feedback condition  $\times$  Task interaction was not significant (see Table 1).

Text analysis

General text quality. Two judges assessed the quality of the texts in terms of informational content and language usage using a 7-point scale (from 1 to 8, the higher score reflecting the highest quality). When the two judges disagreed on the scoring of a text by 2 points or more, they were asked to discuss their scoring until they reached agreement. Subjective judgements of text quality were averaged across the two judges, given that the inter-rater reliabilities were statistically significant. The values of Pearson's  $r$  were .81 for language usage and .87 for informational content ( $p < .0001$ ). A 2 (Feedback condition: feedback, no feedback)  $\times$  2 (Scale: language, information) analysis of variance with repeated measures on the last factor was conducted. As can be seen in Table 2, no reliable effect of the feedback condition was observed (feedback:  $M = 4.9$ ; no feedback:  $M = 4.9$ ). Across the two feedback conditions, language score was judged better

(5.2) than informational content,  $M = 4.6, F(1,38) = 12.66, p < .05$ . The Feedback condition  $\times$  Scale interaction was not significant (see Table 2).

Text-based variables. The analysis revealed neither a reliable effect of the suppression of visual feedback nor a reliable interaction on the syntactic structure (expressed by the number of words per clause, words per sentence, and clauses per sentence) and on the number of spelling and grammatical errors (see Table 2).

DISCUSSION

The experiment presented in this article aimed at investigating the effects of the suppression of visual feedback during text composition on the processing demands and coordination of the low- and high-level writing processes. RT interferences associated to handwriting during a copying task and to pausing and handwriting during a composing task were analyzed. Writers' productivity variables and text quality related variables were collected.

Results show that RT interference associated with pauses during text composition was not significantly different in the feedback and no feedback writing conditions. By contrast, RT interference associated with handwriting during copying was longer without visual feedback than with visual feedback. Because mean RT interference associated with handwriting during a copying task evaluated the processing demands of execution processes (see introduction), the present experiment clearly supports the idea that suppression of visual feedback increases the processing demands of execution processes but not those of high-level writing processes (formulating and monitoring processes). One can argue that this finding, namely that the suppression of visual feedback affects the processing

**TABLE 1**  
Volume of texts and number of words per minute in the feedback and no feedback writing conditions

Dependent measures	Writing condition	
	Feedback	No feedback
Volume	199.0 (15.6)	263.0 (24)
Fluency (wpm)		
Composition	14.5 (1.2)	13.9 (0.8)
Copy	21.0 (1.7)	20.6 (0.9)

The figures in parentheses are standard errors.

**TABLE 2**  
Scores of writing quality in the feedback and no feedback writing conditions

Dependent measures	Writing condition	
	Feedback	No feedback
<i>Quality judgements</i>		
Language	5.3 (0.3)	5.2 (0.3)
Information	4.6 (0.3)	4.5 (0.3)
<i>Syntactic structure</i>		
Clause length	8.8 (0.4)	8.4 (0.2)
Sentence length	20.2 (1.1)	20.3 (0.9)
Sentence complexity	2.4 (0.2)	2.6 (0.2)
<i>Errors (by word)</i>		
Spelling	0.013 (0.008)	0.004 (0.001)
Grammatical	0.030 (0.013)	0.014 (0.002)

The figures in parentheses are standard errors.



demands of execution processes, is not new (Graham & Weintraub, 1996; Smyth & Silvers, 1987; Van Doorn & Keuss, 1992, 1993; Van Galen et al., 1989; Zesiger, 1995). However, by contrast with previous research (see introduction), in the experiment described in this article we were able to analyze the processing demands of both the low- and high-level writing processes of each writer. By contrast, all the other studies that have investigated this issue have analyzed the processing demands of the low-level and high-level writing processes separately. Further, in the studies that have reported the effects of the suppression of visual feedback on execution processes, participants were involved only in letter or word production tasks. It is the first time that the increase of the processing demands of execution resulting from the suppression of visual feedback has been observed during a composition task. In sum, we have gathered evidence that visual feedback only affects motor transcription and not high-level writing processes *during text composition*, and this supports the claim that visual feedback is used to erase motor programmes already executed from working memory.

Consistent with this interpretation, none of the textual analysis conducted in the present experiment revealed an effect of the suppression of visual feedback. Syntax, mechanics, or the general quality of the texts were not affected. This absence of effect strongly supports the suggestion that high-level processes were not affected by either the suppression of visual feedback or the increase of processing demands of execution processes. One could argue that the absence of effect of the suppression of visual feedback on text quality could be due to the composition task used in this experiment (composing about a familiar topic), which may have been too easy for writers. For instance, it is more likely that this kind of topic might have induced the use of a well-practised script, as in Gould's experiment (1980), or may have elicited writers to express common ideas in their text. This may explain why judges were unable to differentiate the texts produced with visual feedback from the texts produced without visual feedback. However, two lines of evidence can be raised against this argument. First, the type of text that writers were asked to compose, namely an argumentative one, is considered to be one of the more complex types of text that can be produced, engaging large processing demands (Kellogg, 1994) and implying knowledge transformation and high linguistic skills (Coirier & Andriessen, 2000). Second, the same topic as that used in this experiment has already been used in several experiments and has created conditions in which writers fully engaged high-level writing processes (Kellogg, 1987; Olive, Piolat, & Roussey, 1997).

The results on writers' fluency are another source of convergent findings supporting the idea that suppression of visual feedback does not affect high-level writing processes. According to McCutchen (1988) and Levy and Ransdell (1995), fluency is a direct indicator of the amount and quality of operation of high-level writing processes. Consequently, when the operations of these processes are affected, the writer's fluency should decrease. Fluency was

not reliably modified by suppression of visual feedback, suggesting again that suppression of visual feedback did not affect high-level writing processes.

It has been reported that an increase in the processing demands of execution processes can interact with high-level writing processes and affect their efficiency (Brown et al., 1988; Fayol, 1999). For example, in a written serial recall task, Bourdin and Fayol (1994) observed that writers recalled fewer items when they used an unfamiliar calligraphy than when they used their usual and well-practised calligraphy. In the present experiment, because processing demands of execution had been increased by the suppression of visual feedback, such an interaction should have been observed. However, in the present experiment, this interaction has presumably not occurred because the writers who composed without visual feedback changed the way in which they managed the written composition task. When visual feedback was suppressed, in other words when the processing demands of execution were increased, writers were unable to activate the low- and high-level writing processes concurrently during the execution of their text in the composition task; instead, they adopted a step-by-step strategy of coordination of the writing processes. Indeed, writers who were allowed to use visual feedback during the composition task concurrently activated the low- and high-level writing processes. In the feedback writing condition, interference reaction times were longer when the probes occurred as writers were handwriting their text during text composition than during copying and than when pausing during text composition. This increase in reaction time during handwriting in text composition indicates that both low- and high-level writing processes were activated. By contrast, in the no-feedback condition, interference reaction times associated with handwriting-copying (i.e., with execution) and with transcription-composing did not differ.

The results of the present experiment corroborate the findings by Olive and Kellogg (in press) and support the claim that the extent to which working memory resources are limited determines whether or not writing processes are activated concurrently. More precisely, a concurrent coordination of the low- and high-level processes can be observed only when writers have achieved automaticity in writing processes, and in particular, automaticity of the low-level execution processes. As Olive and Kellogg observed, in the present experiment, where the processing demands of execution were increased by suppressing visual feedback, writers also adopted a step-by-step strategy of management of the low- and high-level writing processes. In their experiment, Olive and Kellogg (in press) used the same method as the present experiment. But because writers composed their text with their usual handwriting in the present experiment, operations of execution were not transformed as for adults in Olive and Kellogg's experiment. Nevertheless, the same pattern of on-line coordination of the writing processes as that found in Olive and Kellogg's study was observed here when writers were able to compose their text in the standard and familiar condition. All these convergent findings strongly support



the view that the processes engaged in written composition compete for a common pool of working memory resources (Kellogg, 2001).

One goal that guided us in designing the method used in the experiment presented in this article was to design a method enabling us to isolate the high-level writing processes. In particular, we assumed that when probes occurred during pauses in text composition, writers were mainly engaged in high-level writing processes. However, as noted in the introduction, writers might also be engaged in thoughts unrelated to the composing task (e.g., daydreaming). Thus, mean reaction time interference associated with probes during pauses might evaluate processing demands other than those of high-level writing processes. Because the method used in this experiment does not allow the detection of such thoughts, it was not possible to exclude from the analysis reaction times to probes associated with these thoughts. Consequently, this can limit our interpretation that the processing demands of the high-level writing processes were not affected by the suppression of visual feedback. Nevertheless, some data indicate that such unrelated thoughts are generally very scarce in experiments on text composition. The triple task method is aimed at studying the processing demands of the writing processes by asking participants to compose a text while they simultaneously respond to secondary probes and perform a verbalization task (which can be directed or not). The verbalization task is particularly aimed at providing information on the writing processes that are activated when the probes occur. Verbalization data from the numerous studies that were conducted using the triple task method (for a review, see Olive et al., 2001) indicate that such daydreaming activity and unrelated thoughts occur less than 1% of the time. It is thus possible to assume that in the present experiment such thoughts were also this scarce and that reaction time to probes occurring during pauses mainly reflected the processing demands of the high-level writing processes.

Further experiments should confirm the results reported here. For example, future research should focus on the quality of handwriting by adopting within-subject designs. Further, kinetic measures of handwriting should also give evidence on how writers adapted their handwriting to the suppression of visual feedback. For instance, when visual feedback is suppressed, the increase in processing demands should result in prolonged movement times. According to Zesiger (1995), vision appears to erase motor programmes already executed from a motor and/or a graphemic buffer. Finally, to improve our understanding of the role of vision in text composition, more attention needs to be directed to the more detailed effects of the suppression of visual feedback on text structure and text quality, and particularly on the semantic analysis of text. This may provide crucial information concerning the relationship between high-level writing processes and the text already written.

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