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Age Differences in Learning from Instructional Animations

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Summary: The present study tests the effects of the decline of executive functions and spatial abilities with aging on the comprehension of a complex instructional animation. An animation of a piano mechanism was presented individually to 33 young adults and 31 elderly participants. Two presentation speeds of the animation (normal and slow) were compared in a 2 × 2 experimental design. Eye movements were recorded during the learning time. Then, four executive function tests (inhibition, shifting, updating, and processing speed) and a spatial ability test (differential aptitude test) were undertaken by each participant. Results showed that the comprehension of animations was significantly affected by aging. Significant differences between young and old groups were found for executive functions and spatial abilities. Regressions on comprehension scores showed a strong significant effect of spatial ability. Like in previous research, presentation speed had no effect. Eye movement data showed this result was due to application of a compensation strategy. Copyright © 2015 John Wiley & Sons, Ltd.

INTRODUCTION

Instructional animations provide direct temporal information about dynamic phenomena (Bétrancourt, 2005; Hoffler & Leutner, 2007). However, their transient character may present considerable processing challenges to learners' working memory (Lowe & Schnotz, 2008, Mayer, 2009). Compared with static graphic depictions, animations cause cognitive load (Ayres & Paas, 2007a, 2007b; Boucheix, 2008; De Koning, Tabbers, Rikers, & Paas, 2007, 2009; Hasler, Kersten, & Sweller, 2007; Kalyuga, 2007; Lowe, 1999, 2003; Lowe & Boucheix, 2008; Mayer, Hegarty, Mayer, & Campbell, 2005; Moreno, 2007; Paas, Van Gerven, & Wouters, 2007; Rasch & Schnotz, 2009; Spanjers, Van Gog, & Van Merrienboer, 2010; Verhoeven, Schnotz, & Paas, 2009; Wouters, Paas, & Van Merrienboer, 2008; Wong, Leahy, Marcus, & Sweller, 2012).

Individual differences influence the extent of those cognitive demands for a particular learner. Previous research on complex dynamic visualization showed consistently that young adults with higher spatial ability performed better than those with low spatial ability (Boucheix, 2008; Boucheix & Guignard, 2005; Boucheix & Schneider, 2009; Hegarty, 2004, 2005, 2010, 2011; Hegarty & Kozhevnikov, 1999; Hegarty, Kriz, & Cate, 2003; Hegarty & Sims, 1994; Hegarty & Steinhoff, 1997; Hegarty & Waller, 2005; Höffler, 2010; Höffler & Leutner, 2007, 2011; Kriz & Hegarty, 2007). Further, spatial ability performance tends to decline significantly with aging (Dobson, Kirasic, & Allen, 1995; Hertzog & Rypma, 1991; Salthouse, 1994). Also, executive functions and processing speed of working memory undergo a progressive decline with age (Feyereisen & Van der Linden, 1992; Fisk & Warr, 1996; Raz, 2000; Salthouse & Babcock, 1991). Therefore, one might expect that the treatment of complex dynamic visualization may be impaired in the elderly.

The present study examined how old and young learners understand and build a mental model from a complex instructional animation. The goals of the experiment reported in this article were as follows: (i) to test whether the presentation speed of the animation would influence comprehension and the quality of the mental model built from the animation in young and old learners and (ii) to test whether the possible decline of spatial abilities, executive functions, and processing speed with age would have an effect on the understanding of the animation. In addition, in order to analyze online processing of the animation during learning time, an eye-tracking method was used to complement off-line measures of comprehension.

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Animation processing challenges, the animation processing model

The animation processing model (APM) provides a general framework describing how learners process complex explanatory animations (Lowe & Boucheix 2008). This hierarchical framework specifies five processing phases involved in the progressive building of a high-quality mental model. A detailed description of this model can be found elsewhere (Boucheix, Lowe, Putri, & Groff, 2013; Lowe & Boucheix, 2008). Figure 1 illustrates the first three stages.

In the first phase, learners must parse the animation's continuous flux of dynamic information into individual *event units*. An event unit consists of an entity plus its associated behavior. The concept of *event unit* is central to the APM and has its origins in the work on event cognition by Zacks and colleagues (e.g., Kurby & Zacks, 2007; 2011; Zacks, Speer, Swallow, Braver, & Reynolds, 2007). During this parsing activity, the learner is engaged in a broad perceptual exploration of the animation, at a local level. And there is a competition for attention between co-present event units in the context of a limited time resource (cf. Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Spanjers et al., 2010).

Phase 2 processing involves the linking of local segments into broader event structures for which Lowe and Boucheix (2008, 2011) coined the term *dynamic micro-chunks*. In Phase 3, sets of *dynamic micro-chunks* are inter-connected with meaningful domain general relationships to form causal chains, or spatiotemporal schemas that characterize the main aspects of the system's operation (Kriz & Hegarty, 2007; Lowe & Boucheix, 2008, 2011).

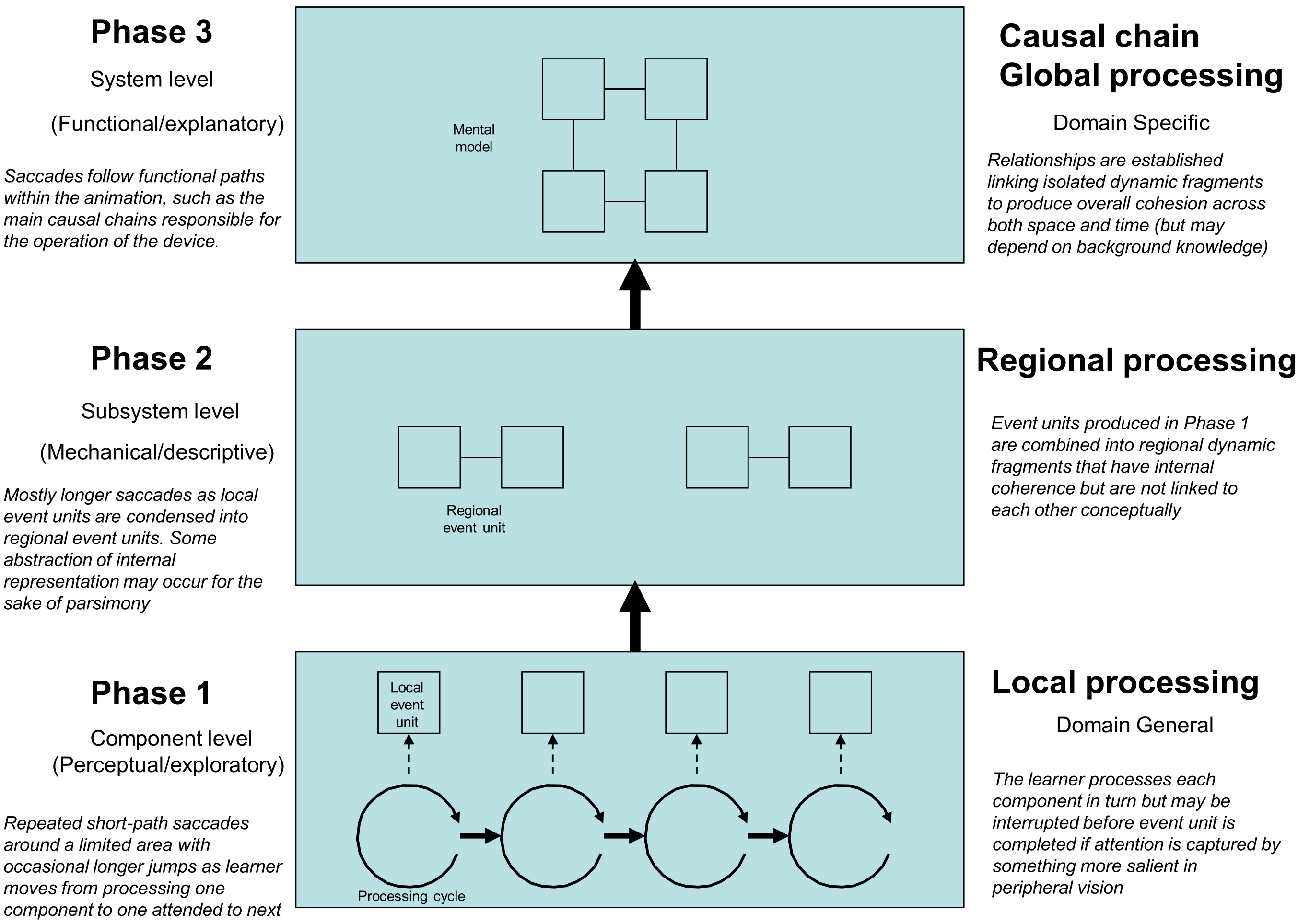


Figure 1. The first three stages of the animation processing model (Lowe & Boucheix, 2008)

In Phase 4, more abstract and superordinate functional episodes of events are constructed. Finally, Phase 5 consists of a high-level generalization stage devoted to the consolidation of a flexible high-quality mental model. The present study focuses on earlier activities of animation processing (APM, Phases 1, 2, and 3, Figure 1).

Processing difficulties could arise at each of the different stages of the model. Perceptual and attentional difficulties are more likely to occur during Phase 1, while cognitive difficulties, related to the integration of events into chunks, are more likely to appear for the upper phases, 2 and 3 (see also Kurby & Zacks, 2011; Zacks, Speer, Vettel, & Jacoby, 2006).

Animation speed of the presentation, processing strategies, and aging

According to the processing speed hypothesis (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Miyake et al., 2000; Salthouse, 1991, 1996), mental operations slow down with aging and require extra time. Realistic animations are often presented with their natural time, usually with fast temporal rates. Such speed rates could exceed working memory capacities (Fischer & Schwan, 2008; Höffler & Leutner, 2007; Lowe & Schnotz, 2008; Ploetzner & Lowe, 2012). As a result, high presentation speed may have a negative effect on the comprehension of instructional animations in older viewers.

To date, only a limited number of research have studied the effect of speed of the presentation of the animation on comprehension (Boucheix & Lowe, 2012; De Koning, Tabbers, Rikers, & Paas, 2010; Fischer, Lowe, & Schwan, 2008; Fischer & Schwan, 2008; Meyer, Rash, & Schnotz, 2010). Unexpectedly, results from these studies, on different contents areas (cardiovascular system, four-stroke engine, operating mechanism of a pendulum clock, and kangaroo's hopping) were mixed.

Overall, presentation speed had no significant effect on comprehension performances but influenced the nature of the cognitive processes developed during the learning time. The low-speed groups reported investing more mental effort to obtain this performance than did the high-speed groups, De Koning et al., 2010. Eye-tracking investigations (Meyer, Rash, & Schnotz, 2010) indicated that high presentation speeds accentuated global events processing (i.e., macro-events), whereas low speeds accentuated local events processing (i.e., micro-events). Previous research concerned young adults, and the question of whether for old participants, compared with high-speed presentation, low-speed presentation of the animation would improve comprehension of complex dynamic systems arises.

Further, in order to cope with the speed constraints, the type of strategy used by learners to process the animation during the learning time could differ according to the animation's presentation speed. Specific processing strategies could be used to compensate the effect of the animation's speed. For example, during the overall learning time, within a fixed number of user-controlled replays of the animation, the time spent on the animated phase and on the static phase of the visualization between two replays and before the restarting of the animation could be differently balanced according to the speed of the animation. In the slower-speed condition, learners could have enough time to process most of the dynamic events, with their relations during the animation delivery time. Few additional processing of the mechanism could be required during the following static phase of the presentation.

Conversely, in the faster-speed condition, because of an overwhelming effect, learners may not have enough time to process most of the dynamic events, and their relations, during the animation delivery time. Accordingly, a cognitive compensation mechanism for this difficulty might appear that would consist of spending more time on the static phase of the presentation in order to continue to internally process or mentally simulate (Hegarty, 2004, 2011; Hegarty et al., 2003) the dynamics of the mechanism from the static presentation.

This supposed strategy could be assessed using eye-tracking measures such as the fixation duration on different areas of interest (AOIs) of the display (piano pieces) for the two different phases of the animation's presentation, dynamic and static. The use of a compensation mechanism would result in higher fixation durations on the AOIs (piano pieces) in the static phase of the piano than in the animated phase for the faster-speed presentation. On the contrary, we would expect higher fixation duration in the animated phase than in the static phase for the slower-speed presentation. An interaction between presentation speed and animation phases was expected for the eye movement data. Furthermore, speed-task-related adaptive behavior could also vary as a function of the age of the learners.

Aging, spatial abilities, and other cognitive abilities potentially involved in animation processing

To our knowledge, research in the area of instructional animation including spatial ability measures has not involved older adult participants yet. And it is known that spatial ability performances tend to decline significantly with aging (Dobson et al., 1995; Hertzog & Rypma, 1991; Salthouse, 1990, 1991, 1994). Because spatial abilities are involved in complex visualization processes, a difference between young and old learners in animation processing and comprehension could be expected.

Further, because of the transient character of dynamic visualizations, executive functions of working memory, and also the individual information processing speed across the temporal stream of the animation, could have an effect on animation processing efficiency (Bugaiska et al., 2007; Clarys, Bugaiska, Tapia, & Baudouin, 2009; Miyake et al., 2000; Moscovitch & Winocur, 1992; Parkin, 1997; West, 1996). No studies about comprehension of visualization already included measures of executive functions and processing speed.

Executive function components usually include three main cognitive dimensions (Miyake et al., 2000, 2001).

i. Inhibition is the ability to inhibit proponent and irrelevant information.
ii. Shifting, or mental set shifting, is the ability to switch selectively attention from one target information to another. Shifting is related to mental flexibility.
iii. Updating concerns the processes of continuous information updating during learning activities.

Inhibition processes could be involved in the ability to select (quickly) content-relevant but inconspicuous dynamic events rather than events with more perceptual salience but less relevance. Shifting ability could be involved when learners need to switch (alternatively) from one location to another because simultaneous events occur in the animation.

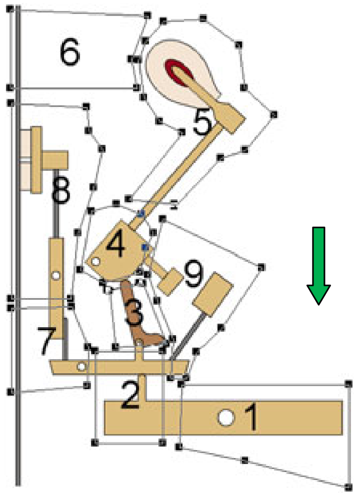
Cognitive processing challenges with complex animation

The present study used the animation (without text) of an upright piano's hidden mechanism (Figure 2), a subject matter that is both complex and unfamiliar to most people (Boucheix & Lowe, 2010; Boucheix et al., 2013; Boucheix, Lowe, & Soirat, 2006; Lowe & Boucheix, 2008, 2011).

This animation has a number of features that are of special relevance with respect to the learning challenges involved. First, all the entities and events are perceptually available, with nothing important being hidden. Second, the piano mechanism is a typical example of a realistic animation (Lowe, 2003, 2004) that shows multiple simultaneous events, changing in different ways across space and time. The overall internal mechanism by which a musical note is produced when a pianist presses a key on a piano keyboard consists of a system of levers and pivots, which operates in three main phases (Figure 2).

Across these three phases, a series of related events are running very rapidly and overlapping in time. Two functional subsystems operate simultaneously, via two causal chains: the hammer subsystem and the damper subsystem. The piano example also offers a typical case of misalignment of perceptual salience and thematic relevance. For example, the hammer and the damper are perceptually salient because they are large, in size, and also in the amplitude of their movements. These two parts are fundamental to the functionality of the mechanism (striking the string and freeing the sound). However, other parts that are also central in the operation of the upright piano (such as the whippen, the jack, and the position of the end of the key) are smaller, and less visually salient.

The structure of a mechanical animation, such as the upright piano, offers the possibility to measure at least three levels of performance with respect to the memorization and comprehension of the device. Two of these levels were identified by Narayanan and Hegarty (1998): (i) the spatial configuration of the piano system's parts and (ii) the (local) kinematics of the system with respect to both the presence and direction of motion of each component part. We recently added a third level: the overall quality of the functional mental model of the piano system in which all component parts and kinematics are integrated for the system as a whole (Boucheix & Lowe, 2010).



Eye tracking Area of Interest

1- Key
2- Whippen
3- Jack
4- Hammer-Butt
5- Hammer
6- Hammer (after move)
7- Damper spoon
8- Damper
9- Balance Hammer and Back-check

Phase 1. When the pianist presses the key; it moves the key-sticker at the end of the key upwards. The key-sticker then raises the whippen causing it to make a rocking motion as a result. This raising of the whippen operates the jack by pushing it upwards which in turns pushes up the hammer butt. The hammer-butt then pivots on its axle and so projects the hammer toward the string, which it strikes to produce the note. Simultaneously, the rocking motion of the whippen also pushes the damper so that it lifts off the string, and allows sounding freely. This lifts the damper off the string so that the string can sound freely when struck by the hammer.
Phase 2- Once the hammer has struck the string, it instantly rebounds backwards. To limit the hammers' backward motion, the balance hammer is caught and blocked by the back-check. The system is held in this position for as long as the key remains depressed by the pianist.
Phase 3- When the key is released, the whippen drops, the back check releases the balance hammer, and the jack then moves downward under the butt with the hammer returning to its initial position **(End)**. At the same time the damper returns to the strings.

Figure 2. The upright piano mechanism

Dependant measures of the study were directly related to these performance levels. Two comprehension tasks were used. With Task 1, the first two levels, *configuration and local kinematics*, were assessed with the responses to a multiple-choice comprehension questionnaire. This questionnaire was composed of a series of questions such as, for example, for the *configuration level*, 'which parts touch the key?' and, for the *local kinematics* of the system, 'Does the whippen move? Up or down?' This dependant measure, labeled *configuration–kinematics* in the following sections of the paper, is mostly related to the first two levels of the APM, which rely on perceptual levels of processing (Figure 2).

With Task 2, the third level, *the mental model quality*, was assessed with an open-ended written task: 'Write as much as you can about what happens with all parts of the system when someone presses the key down and then releases it'. This latter task was usually considered as one of the most sensitive and discriminating task for measuring mental model quality in the literature about multimedia comprehension (Mayer, 2009). The mental model score labeled 'mental model' in the following sections of the paper is related to the upper stages of the APM, Stages 3 and 4.

Hypotheses

Four hypotheses were stated, closely tied to the theoretical aspects developed in the preceding sections.

i. Because spatial ability performance tends to decline significantly with aging and also executive functions and processing speed of working memory undergo a progressive decline with age, processing of complex dynamic visualization could be impaired in old people. *Hypothesis 1* would predict a decrease in comprehension performances for dynamic visualization with increasing age.
ii. Because previous studies failed to show a conclusive effect of presentation speed on the overall comprehension measures in young learners, it is an open question, *Hypothesis 2*, whether presentation speed would affect comprehension scores in older learners.
iii. Because spatial abilities are involved in animation processing, *Hypothesis 3a* would predict that the effect of spatial abilities on comprehension should be more marked in old participants than in younger participants. Similarly, if executive functions and processing speed are involved in comprehending dynamic visualizations, *Hypothesis 3b* would predict that their potential decline with aging should impair animation understanding performances.
iv. Regarding the occurrence of a potential compensatory mechanism, *Hypothesis 4* stated that in the case of low presentation speed, learners would be able to extract both component properties and their associated events during the running of the animation. Such a processing strategy could be very difficult to apply and to maintain thoroughly in the case of higher speed. In this latter case, the extraction of information related to components,

events, and their relations could be distributed across the static phase and the dynamic phase of the animation study. The fixation time spent on the relevant AOIs of the visualization (Figure 2) during the static phase and the dynamic phase should reflect evidence in favor of the use of a compensating strategy.

METHOD

Factors in the 2 × 2 experimental design were animation speed (fast versus slow) and age group (young versus old).

Participants

A total of 64 adults living in a medium-sized French metropolitan area participated in the study. They were divided into two groups: The first consisted of 33 young adults (undergraduate students, age range 18–27 years, 28 women and 3 men) and the second of 31 elderly adults (age range 61–85 years, 29 women and 2 men). The older adults lived in their own homes and were recruited from a pool of different associations. They were screened for possible dementia with the Mini-mental State Examination (MMSE, Folstein, Folstein, & McHugh, 1975), and only subjects who obtained a score above the cutoff of 27 points (out of 30) on the MMSE were included in the study. All participants were volunteers and reported themselves to be in good physical and mental health and free from medication known to affect the central nervous system. All participants were European and belonged to the same ethnicity. Demographic characteristics of the two groups are shown in Table 1.

As shown in Table 1, the groups did not differ on years of education. Before the beginning of the experiment, a short questionnaire was used for the assessment of prior knowledge on piano mechanisms, the use of screens and computers, visual acuity, study level, and health. None ($n = 0$) of the participants selected for the experiment had prior knowledge about mechanical piano systems, and so all were novices regarding the content of the animation. All participants in both groups had (corrected) normal visual acuity, all were healthy, and participants in both groups had screen and computer familiarity.

Apparatus and materials

Each participant undertook an individual experimental session, using the tasks, materials, and apparatus described in the following.

Table 1. Means and standard deviations of participant's characteristics for the two age groups

	Young ($n = 33$)		Old ($n = 31$)		
	M	*SD*	*M*	*SD*	$t(62)$
Age (in years)	20.15	1.68	68	6.39	
Mini-mental State examination	—	—	28.74	1.09	
Education (years)	13.78	0.74	12.60	3.40	1.9 (ns)

Animation presentation

The animated sequence of the upright piano mechanism (Figure 1) ran straight through from start to finish (no user control). Each learner watched it 10 times in succession. The fast version ran for 4.2 seconds per complete cycle (including start and ending times), while the slow version ran for three times as long at 12.7 seconds. The choice of the times of the fast and slow versions, as well as the choice of the number of presentations (10 times), was based on previous studies using the same piano mechanism (Boucheix & Lowe, 2010; Boucheix et al., 2006, 2013; Lowe & Boucheix, 2010, 2011). These previous studies all showed that, given the intrinsic complexity of the mechanism, a series of 9–10 presentations was usually taken by participants in an unconstrained time study of the piano mechanism task (Boucheix et al., 2013). Such a number of presentations were required to reach a basic comprehension level of the causal chains of the system.

Further, in order to investigate potential compensating strategies for fast speed rates, but also to prevent learners from overwhelming effects particularly in older people, initiation of each exposure was self-paced. And at the end of each exposure, the piano remained static until the learner restarted the animation. Restarting the animation involved simply pressing the computer mouse or any key of the computer keyboard. Both slow and fast versions had pop-up labels available to show piano part names that could be viewed at any time via computer mouse rollover.

Spatial ability test

An abbreviated (Part 4: spatial relations) French form of the widely used differential aptitude test (DAT, Bennett, Seashore, & Wesman, 1973, 2002) was used to assess spatial ability. This test measures the ability to mentally rotate figures (Boucheix & Schneider, 2009; Hegarty, 2010; Höffler & Leutner, 2011). The French reference normalization table for this test is composed of 11 levels (Bennett et al., 1973, 2002, normalization table, p. 74).

Executive function tests

The executive function measures were composed of four subtests that are commonly used in neuropsychological assessment (Miyake et al., 2000, 2001) and assessed the four main executive functions: (i) inhibition; (ii) shifting; (iii) updating; and (iv) processing speed.

i. For inhibition ability, the Stroop (1935) test was used. This test was composed of three lists of items (each on one paper page). The first list (L1) contained a series of words that were names of colors printed in black. The second list (L2) was made of a series of printed groups of colored crosses on a sheet of paper (the number of groups of crosses was the same as the number of words in List 1). The third list (L3) contained a series of words that named colors. However, each word is printed in a color that is different from the meaning of the written word (e.g., the word 'red' was printed in green). This last subtask requires an inhibition of the irrepressible, automated tendency to read the word. An interference score was computed as follows: color–word interference score − [(word reading score × color naming score)/(word reading score + color naming score)].

ii. Shifting ability was assessed with the ‘plus–minus’ test (adapted from Jersild, 1927) intended to measure mental flexibility in working memory (Miyake et al., 2000). This test consisted of a paper-and-pencil task composed of three boards of 30 two-digit numbers. Participants were told to add 3 to each number on the first board, subtract 3 from each number of the second board, and sequentially alternate between adding 3 and subtracting 3 from the numbers on the third board. The experimenter measured time on each of the three lists (in seconds). The resulting measure was shifting cost, as calculated by subtracting the mean total time on addition-only and subtraction-only lists from total time on the alternating list.

iii. General updating ability was measured by the ‘*N*-back’ task (Gevins & Cutillo, 1993). In this test, a series of letters ($n = 30$) was presented aurally to the participants. For each letter of the stream of letters, each participant had to decide whether this last letter was present within the three previous letters just given before. The score was the number of correct responses.

iv. The processing speed task was assessed by the letter comparison test (Salthouse, 1990). Participants were presented with a page containing pairs of letters (e.g., X–O). The participants were instructed to decide (as fast as possible) whether the two members of the pair were identical or not and to tick the ‘identical’ or ‘different’ column accordingly. The measure was the number of items answered correctly within 30 seconds.

All the aforementioned tests were administrated in individual sessions and completed in less than 30 minutes.

Off-line comprehension tests: learning outcomes

The multiple-choice task items, *configuration–kinematics*, was the first learning outcome-dependant measure of comprehension and concerned the memorization of the following: (i) *the configuration of the piano system’s parts* (including seven items, e.g., ‘which parts touch the key?’ and ‘the whippen touches the spoon? True or false?’) and (ii) *the local kinematics of the components* of the mechanism with respect to both the presence and direction of motion of each part (including 16 items, e.g., ‘Does the whippen move? If yes, up or down?’ and ‘the damper causes the striking of the hammer on the string? False or true?’).

The open-ended task, *mental model* was the second learning outcome and was a writing task that assessed the overall functional quality of the mental model of the piano system involving integration of all component parts and kinematics. The instruction of the task was ‘write precisely, as much as you can, about what happen for all the components of the system when a pianist presses the key and then releases it’. In order to avoid difficulties related to the recall of technical names of the components, participants were also given a sheet of paper upon which labeled pictures of the piano components were shown separately in random positions.

Responses to these two learning outcome tasks, *configuration–kinematics* and *mental model,* resulted in two comprehension subscores: one for the multiple-choice task with *configuration–kinematics* and one for the writing task on the functional *mental model* quality. For *configuration–kinematics,* answers were right or wrong regarding the real position and behavior of each component of the piano mechanism. So scoring was based on a predetermined grid of answers, with 1 or 0 point being awarded per item for correct or incorrect answers, respectively (maximum 23 points). The *mental model* quality scoring guide was based on the 15 micro-steps constituting the three main stages of a piano mechanism’s functioning (Appendix A). Each correct micro-step was awarded 1 point if fully and precisely reported or half a point if reported only in part. For each micro-step incorrectly reported, half a point was deducted from the score. Participants’ answers were rated by two independent raters; inter-rater agreement, chance-corrected Cohen’s kappa, was 0.94. Scores on each learning outcome measure, *configuration–kinematics* and *mental model*, were transformed into percentages of total possible score on submeasures.

Eye-tracking equipment and online eye-tracking measures

Eye movements were recorded with a Tobii (Danderyd, Sweden) 120-Hz corneal reflectance and pupil center eye tracker. The computer screen for displaying the animation was positioned approximately 60 cm from the participant. Data were recorded with Tobii Studio software. Several eye-tracking indicators were employed on the basis of nine AOIs, each of which corresponded to a functionally relevant component part of the piano system (Figure 1). The type and size of the AOIs chosen across the display were the same for both speed and group conditions. Each of these AOIs was defined with sufficient scope to include the boundaries of the particular piano parts’ entire movement during its operational cycle (so event areas were included in each of the AOIs). Two main types of analyses were performed, both using duration of fixations in the different AOIs. The first analysis was carried out on the total viewing (fixation dwell time) duration in each type of AOI for the whole learning time across the 10 runs of the animation. The second type of investigation included more time-locked analysis (Hyönä, 2010; Hyönä, Radach, & Deubel, 2003; Van Gog & Scheiter, 2010) across the 10 trials.

Eye-tracking data coding criteria

For total viewing duration across time on task, AOIs for the nine piano components were used in all conditions (Figure 1). A further excluded AOI category was also used, which covered all not-on-AOI areas such as the regions between the components of the piano mechanism and AOIs, for example, containing the area for controlling the starting/restarting of the animation (Figure 1) and the spaces between the other nine AOIs. Total viewing duration in each of the 10 AOIs across the time on task was determined.

For the time-locked analysis, two phases were distinguished within the total viewing time in all the AOIs for each of the 10 presentations. The *animated phase* corresponded to the time when the piano is dynamic, for example, moving from the starting time to the ending time of the animation (only the starting time was learner paced). The *static phase* was the time when the piano remains still, just after the ending of a complete cycle of the animation and just before the restarting of another cycle of the animation.

For each of the 10 times the piano animation was played, the two durations of animated and static phases were separated. All the viewing times spent in the different AOIs of the piano mechanism during the animated phase were then summed across the 10 presentations of the animation. All the viewing times in the different AOIs of the piano mechanism during the static phase were also summed across the 10 presentations. This time-locked analysis resulted in splitting the dependant variable (DV) fixation duration in AOI measure into two subsets: total viewing duration on AOIs in the animated and static phases.

Procedure

Participants of each age group were randomly assigned to one of the two speed conditions. The experiment was run on an individual basis with participants seated at the computer and instructed to study the animation in order to understand the depicted mechanism in preparation for a subsequent comprehension test. The eye tracker was calibrated for each participant immediately prior to the session. All participants were required to view the animation 10 times; however, no limit was placed on animation study times for each cycle of the animation and on the times spent on the static piano picture before restarting the animation. After completing their study of the animation, participants completed the comprehension tests. Finally, each participant undertook the series of tests (the DAT and four executive function subtests) in a counterbalanced and random order. For each participant, the whole experiment took between 45 and 60 minutes.

RESULTS

Learning time

As explained earlier, both the speed of presentation of the animation and the number of exposures to the animation (10) were controlled across groups and animation speed conditions. However, how quickly the animation was restarted (between two exposures) could differ across participants. This means the overall learning time could vary across groups and speed conditions, as presented in Table 2.

A factorial analysis of variance (ANOVA), with group (old versus young) and animation speed condition (fast versus slow) as two between-subjects factors and total learning time as the dependant measure showed that old participants took a longer time to study the 10 presentations of the animation than younger participants, $F(1, 60) = 4.64$, $p = .035$, $\eta_p^2 = .07$. However, learning time did not significantly differ according to the speed of the animation, fast or slow, $F(1, 60) = 2.03$, $p = .16$, $\eta_p^2 = .03$. Despite the fact that the age difference increases as speed becomes faster (Table 2), there was no interaction between age group and animation speed, $F(1, 60) = 0.069$, $p = .41$, $\eta_p^2 = .01$. Further, learning time overall may not actually be that important, as we broke learning time down into the static and animated phases for the eye-tracking results. In fact, learning time can only differ by age in the static phase—the dynamic phase time is constant within a given speed. This issue will be examined in the eye-tracking results section.

Table 2. Mean learning times (and *SD*) in seconds for each group, and according to each animation speed condition

	Fast		Slow	
	Young	Old	Young	Old
Learning time	132.68 (51.45)	210.16 (191.5)	191.21 (45.38)	225.56 (64.47)

Comprehension scores

Table 3 presents the comprehension performances expressed as mean percentages with respect to the following: (i) *configuration–kinematics* and (ii) *mental model* quality as a function of group (old versus young) and animation speed (fast versus slow).

To test Hypotheses 1 (would comprehension performances be poorer for older participants?) and 2 (would presentation speed influence comprehension in both groups?), a repeated-measure multivariate analysis of covariance with learning time as a continuous covariate factor, age group and animation speed condition as two between-subjects factor, and comprehension levels as a within-subjects factor (with the corresponding two DVs, respectively, *configuration–kinematics* score and *mental model* score) was performed on these data. Results of this analysis showed no effect of the learning time on comprehension performances, $F(1, 59) = 0.13$, $p = .71$, $\eta_p^2 = .002$, but a significant effect of the group, which indicated that the old participants had lower overall comprehension performances than younger participants, $F(1, 59) = 11.\ 63$, $p < .002$, $\eta_p^2 = .16$. There was also no significant effect of the animation speed, $F(1, 59) = 1,\ 41$, $p = .24$, $\eta_p^2 = .02$. Further, comprehension performances were substantially higher for the *configuration–kinematics* score than for the *mental model* quality score, $F(1, 59) = 172.45$, $p < .0001$, $\eta_p^2 = .74$. The interaction between comprehension levels and age group was significant, $F(1, 59) = 5.22$, $p = .024$, $\eta_p^2 = .08$. This interaction revealed that comprehension performance differences between old and young learners were more marked for the *mental model* score than for the *configuration–kinematics* score.

Table 3. Mean percentage (with *SD*) comprehension scores by group and animation speed condition

	Fast		Slow	
	Young	Old	Young	Old
Configuration–kinematics	70.59 *(12.82)*	67.83 *(15.66)*	77.72 *(12.18)*	67.39 *(8.98)*
Mental model	25.88 *(15.07)*	11.78 *(14.25)*	30.00 *(13.77)*	14.37 *(16.68)*
Total	48.23 *(12.78)*	39.80 *(12.37)*	53.86 *(10.52)*	40.88 (10.75)

Table 4. Mean total fixation duration (dwell time in seconds) in each type of areas of interest (AOIs), at different animation speeds, for older and younger participants and during the static and animated phases

	Fast				Slow			
	Old group		Young group		Old group		Young group	
Speed AOIs	Static phase	Animated phase	Static phase	Animated phase	Static phase	Animated phase	Static phase	Animated phase
Nine main AOIs	114.90	29.69	67.20	33.57	72.20	81.80	51.70	100.56
	(126.67)	*(6.89)*	*(36.05)*	*(5.43)*	*(43.04)*	*(17.82)*	*(36.99)*	*(10.62)*
Excluded AOI	24.37	9.99	17.12	8.44	22.10	29.05	13.26	25.66
	(15.68)	(4.81)	(11.62)	(3.26)	(9.45)	(7.29)	(7.96)	(7.58)
Total	139.24	39.70	84.32	42.01	94.30	110.85	64.96	126.22
	(138.49)	*(4.57)*	*(43.99)*	*(4.90)*	*(50.17)*	*(19.24)*	*(41.01)*	*(8.93)*

To study this interaction in more detail, two factorial ANOVAs were performed, one for each comprehension level, with age group and animation speed as two between-subjects factors and, for each analysis, the *configuration–kinematics* score as the DV for the first ANOVA and the *mental model* quality score as the DV for the second ANOVA.

The ANOVA for *configuration–kinematics* score showed a significant effect of age group on performances, $F(1, 60) = 4.32$, $p = .042$, $\eta_p^2 = .07$; no effect of animation speed conditions, $F(1, 60) = 1.13$, $p = .29$, $\eta_p^2 = .02$; and no interaction between age group and speed conditions, $F(1, 60) = 1.44$, $p = .29$, $\eta_p^2 = .02$. The ANOVA for the *mental model* quality score showed a significant effect of age group on performances, $F(1, 60) = 15.7$, $p < .0002$, $\eta_p^2 = .21$; no effect of animation speed conditions, $F(1, 60) = 0.80$, $p = .37$, $\eta_p^2 = .01$; and no interaction between age group and speed conditions, $F(1, 60) = 0.04$, $p = .84$, $\eta_p^2 = .0001$. These ANOVAs confirmed that the effect of age on comprehension was more marked for the *mental model* measure than for the *configuration–kinematics* measure.

Eye movement results: fixation duration in areas of interest and total and time-locked analyses

Viewing durations results (dwell time,[1] means and *SD*) are presented Table 4.

To test *Hypothesis 4*, in order to address the issue of strategies, a repeated-measure multivariate ANOVA was conducted, including age group and animation speed as two between-subjects factors and learning phase (static versus animated) and the two AOI types (the nine main AOIs and the excluded AOI) as two within-subject factors. Fixation duration was the DV. Results of this analysis indicated first of all a significant effect of age group on the overall total fixation duration, $F(1, 59) = 4.26$, $p = .043$, $\eta_p^2 = .07$; but there was no significant effect of the animation speed, $F(1, 59) = 1.80$, $p = .18$, $\eta_p^2 = .03$ (as in the previous analysis on overall learning time, see earlier part of this section). The interaction between age and presentation speed was not significant, $F(1, 59) = 0.88$, $p = .35$.

[1] The data of one old participant were excluded from the analysis because of a low eye movement sample rate (only 60%).

Further, the overall effect of the phase of the animation delivery (static versus animated) was not significant, $F(1, 59) = 2.77$, $p = .10$, $\eta_p^2 = .04$. However, the interaction between animation speed and learning phase was highly significant, $F(1, 59) = 32.54$, $p = .0001$, $\eta_p^2 = .35$. This interaction revealed that in the slow-animation condition, all learners spent a longer time on the animated phase of the presentation than on the static phase, $F(1, 59) = 8.05$, $p = .006$, Cohen's $d = 1.24$; but in the fast-animation-speed condition, learners spent a longer time on the static phase than on the animated phase, $F(1, 59) = 27.54$, $p < .0001$, Cohen's $d = 1.29$. In line with the expectation regarding the strategy issue, learners looked longer at the static state for the fast animation than for the slow animation before restarting the presentation (Table 4).

The interaction between age group and presentation phase was also significant, $F(1, 59) = 7.01$, $p = .01$, $\eta_p^2 = .11$. This interaction indicated that while young and old participants spent the same amount of time in the animated phase, $F(1, 59) = 1.52$, $p = .22$, Cohen's $d = .18$ (which is not surprising because for each speed condition—fast versus slow—the animation duration was fixed), older learners spent much more time than younger learners studying the static phase of the piano mechanism, $F(1, 59) = 8.44$, $p = .005$, Cohen's $d = 0.57$. The interaction Age * Speed * Phase was not significant, $F(1, 59) = 0.12$, $p = .75$ (Figure 3).

At last, and not surprisingly, older and younger learners spent most of the time on the nine main AOIs rather than on the excluded AOI, $F(1, 59) = 142.43$, $p < .00001$, $\eta_p^2 = .71$.

Executive functions and spatial abilities

Results on performances and statistical analyses for the executive functions and spatial ability tests are presented in Table 5. Single-factor ANOVAs were performed, one for each test with age group as the between-subject factor and test performance as the DV (Table 5). These analyses showed significant differences between younger and older learners for inhibition, speed processing and spatial ability, but not for updating and flexibility.

Correlations between comprehension measures and test scores, which resulted in significant differences between the two groups, are presented in Table 6. Correlations

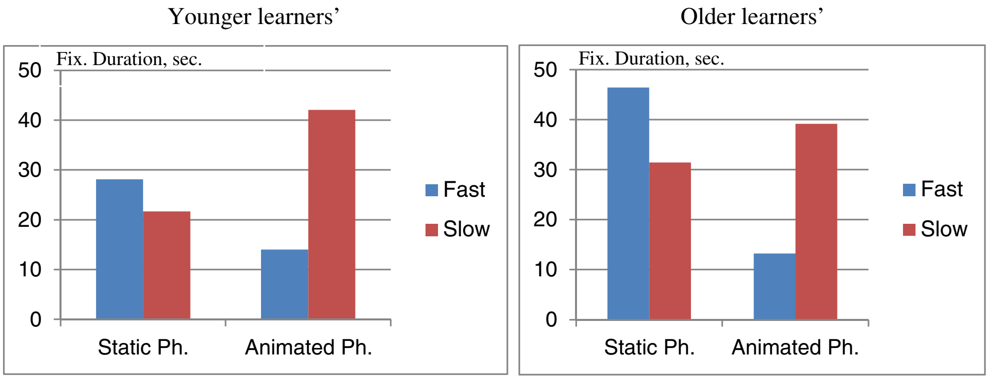


Figure 3. Mean total fixation duration (in seconds) during the static and animated phases for the fast and slow animation, in each age group

Table 5. Scores and means (*SD*) of the two groups for four tests, with *F*, *p*, and η_p^2 values of the five single-factor analyses of variance (ANOVAs)

			ANOVAs		
Type of tests	Younger	Older	$F(1, 62)$	p	η_p^2
Inhibition (Stroop)	6.01 (7.93)	−7.22 (7.62)	46.2	.0001	.41
Updating (Neck–Back)	23.06 (2.80)	22.16 (2.90)	1.59	.21	.02, *ns*
Flexibility (plus–minus)	0.54 (0.08)	0.70 (0.09)	1.62	.21	.02, *ns*
Processing speed (symbols)	24.27 (4.56)	15.00 (4.94)	60.93	.0001	.49
Spatial ability (differential aptitude test)	18.54 (6.35)	10.42 (4.52)	34.34	.0001	.36

Table 6. Correlations between executive function tests, spatial ability test, and post-test comprehension measures (*configuration–kinematics* measure and *mental model* quality measure) for each group separately

Test *r*	Inhibition	Processing speed	Spatial ability	*Mental model*	*Configuration–kinematics*
Inhibition		.18	.42***	.15	.05
Processing speed	***−.23***		.13	.14	−.11
Spatial ability	***−.29****	***.44*****		.39**	.40**
Mental model	***.11***	***.15***	***.50*****		.53***
Configuration–kinematics	**.31***	**.08**	**.45*****	**.33****	

The older group data are in bold at the bottom left of the table, and the younger group data are not in bold at the top right of the table.
***$p < .01$; **$p < .05$; *$p < .10$.

(*r*, Bravais–Pearson) were performed for each age group separately.

In order to study these results in more detail, two stepwise regressions were conducted to analyze the respective effect (the weight) of executive function test scores (for the tests that showed significant differences between younger and older learners: inhibition and speed processing) and spatial ability (DAT) on the following: (i) *mental model* scores and (ii) *configuration–kinematics* scores. In these analyses, executive function and spatial ability test scores are considered as the factors, and comprehension scores are the dependant measures. For the two stepwise regressions, we did not select which predictors would be entered at each step; on the contrary, the software was allowed (STATISTICA 10, StatSoft Inc., Tulsa, OK, USA) to make that determination using its default procedure.

i. The first stepwise regression analysis for *mental model* scores revealed, at the Step 1 of the analysis, that the first significant influential factor was spatial ability, multiple $R^2 = .31$, $F\ (4,\ 59) = 8.25$, $p < .0003$, and $\beta = .44$, $t(59) = 3.20$, $p < .003$. At the following steps of the analysis, the second factor found was age, but not significant, $\beta = -.14$, $t(59) = -0.74$, $p > .05$; the third factor was the inhibition test, also found to be not significant, $\beta = .07$, $t(59) = .52$, $p > .05$; and finally, the speed processing test was also not significant, $\beta = .03$, $t(59) = .17$, $p > .05$.
ii. The second stepwise regression analysis conducted with *configuration–kinematics* scores indicated, at the Step 1 of the analysis, that the first influential significant factor was spatial ability again, multiple $R^2 = .25$, $F(4,\ 59) = 4.93$, $p < .002$, and $\beta = .50$, $t(59) = 3.39$, $p < .002$. At the following steps of the analysis, the second factor found was processing speed, but not significant, $\beta = -.21$, $t(59) = -1.24$, $p = .21$; the third factor was the inhibition, which was also not significant, $\beta = .10$, $t(59) = 0.65$, $p > .05$; and finally, age was again not significant, $\beta = -.07$, $t(59) = -0.34$, $p > .05$. In sum, only spatial ability was found to be significantly influential in the regression analyses.

DISCUSSION AND CONCLUSION

The goals of the present experiment were as follows: (i) to test whether the presentation speed of a complex animation would influence the quality of the mental model built from the animation in young and old learners and (ii) to test whether the possible decline of spatial ability and executive functions with age would affect animation understanding performances. Eye tracking was used in order to analyze on-line processing of the animation during learning time and to complement off-line measures of comprehension.

As predicted with *Hypothesis 1*, younger learners' comprehension scores were better than those of older learners. However, the difference observed between the two groups varied significantly according to the two targeted comprehension level, *configuration–kinematics* and *mental model*. Young and old age groups' learning performance differences were more pronounced for the *mental model* quality level than for the *configuration–kinematics* level. This pattern of results could suggest two alternative explanations.

i. The first explanation assumes that processing difficulties related to aging concerned equally both comprehension levels measures used in the study. The first comprehension level, *configuration–kinematics*, is the event processing level (Lowe & Boucheix, 2008). The second is the *mental model* quality level, which is the integration of events in a more comprehensive, complete, and exhaustive representation of the piano operation. Thus, older learners showed difficulties in the ease of recalling events and also in the ease of connecting and relating accurately events together in order to build broader regional structures (Phases 1, 2, and 3 of the APM, Lowe & Boucheix, 2008).
ii. The second alternative explanation might consider that the major difficulty of older learners is not so much in the ability to segment the local events but in the ability to connect these events together into coherent structures such as causal chains hierarchically organized (Phase 3 of the APM, Lowe & Boucheix, 2008; see also Radvansky & Dijkstra, 2007).

Spatial ability, which strongly declined with age, was found significant in the regression analyses on comprehension scores. Could spatial ability be a candidate to explaining such dissociation between the ability to extract the raw material, such as the local movement of most of the single piano parts, and the difficulty to build from this material more hierarchical structures, such as well-integrated causal chains?

The pattern of correlations found between the two comprehension levels' performances could fit with both explanations. The correlation between the two comprehension levels was significant for the young learners, $r(df\ 32) = .53$, $p < .001$, thus indicating that efficient extraction of well-segmented raw material could be a necessary condition to build broader coherent structures, in order to form a high-quality mental model. However, extracting raw material could not be a sufficient condition to connect local events into broader structures, such as causal chains. For the older group, the correlation between the performances of the two comprehension levels was only marginally significant, $r(df\ 30) = .33$, $p = .065$.

In sum, our results suggest that age differences in the processing and recall of complex explanatory animation could arise firstly from the initial parsing activities (Phase 1 of the APM) of the continuous flux of information into meaningful events (components plus their behavior) and later from the building of hierarchical causal chains (Phase 3 of the APM).

Regarding animation speed, *Hypothesis 2* and, in agreement with previous studies, our results did not show a significant effect of presentation speed for either group. We suggested that a possible reason why no difference was found in animation comprehension at different presentation speeds was the use by learners of processing strategies allowing them to cope with such speed differences and compensate for the high-speed presentation effect. In line with this expectation, our results from time-locked eye movement's analyses showed the following: (i) learners in both groups spent longer time studying the piano mechanism in the static pre-restart phase with the fast version of the animation than with the slow version. For the fast animation, some necessary additional processing could have been postponed from the animated phase to the static phase. Fast-speed animation could prompt the use of a compensating strategy. For example, a mental simulation of the piano mechanism components could occur in the static phase immediately following the animation phase and before restarting the animation. Further, the identification of the configuration of each component (with their labels), and also their functions, could have been performed within the static phase, while the processing of the pure dynamics aspects was performed mainly within the animated phase. By contrast, at the slow playing speed, such compensation and partitioning of the viewing task are less essential, so that all aspects of the piano mechanism were studied mainly during the animated phase.

(iii) Furthermore, this trend to compensate for the effect of speed, by extended interrogation of the animation during the static pre-restart was more pronounced for older learners than for younger learners.

Hypotheses 3 and 4 predicted inferior quality of the mental model built from the animation by the older participants due to their age-diminished spatial ability and level of executive functions. Results showed significant differences between younger and older learners for spatial abilities, inhibition, and processing speed. Stepwise regression of spatial ability and executive function scores on (i) *configuration–kinematics* and (ii) *mental model* quality scores showed that only spatial ability had a significant effect on comprehension scores. It is not appropriate to draw strict causal conclusions from stepwise regression. However, this result provides a strong clue of the possible role of spatial ability decline in the decrease with age of the comprehension of complex instructional animation.

To our knowledge, the present study is the first to specifically investigate relationships between age and instructional animation comprehension. Further research is needed to more precisely characterize the effect of age on the comprehension of explanatory animation and dynamic multimedia presentations. This is a challenging and important matter because of the continuous growth of technology and its pervasive effect on all aspects of everyday life. Easy access to such contents should be provided to old people for learning, life span training, or information delivery purposes.

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APPENDIX A

Scoring guide for the written test of mental model quality

Stage 1: *Striking*

1- When the key is pressed (by the pianist), it moves the key-sticker at the end of the key upwards.

2- The key-sticker raises the whippen that makes a rocking motion as a result.

3- The raising of the whippen operates the jack.

4- The upward-moving jack pushes up the hammer butt.

5- The hammer butt pivots on its axle.

6- The pivoting of the hammer butt moves the hammer toward the string.

7- The hammer strikes the string to produce the note.

8- At the same time, the rocking motion of the whippen pushes the damper to lift it off the string.

9- The release of the damper liberates the string to sound freely when struck by the hammer.

Stage 2: *Recovering*

10- The hammer instantly rebounds backwards once it has struck the string.

11- The balance hammer is caught and blocked by the back-check in order to limit the hammer's backward travel. The system stays in this position as long as the key remains depressed.

Stage 3: *Resetting*

12- When the key is released, the whippen drops.

13- The back-check releases the balance hammer.

14- The jack moves downward under the butt, and the hammer returns to its initial position.

15- At the same time, the damper returns to the string.