Skill acquisition and transfer to contextually different tasks: Complete, partial or zero transfer?

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Skill Acquisition and Transfer to Contextually Different Tasks: Complete, Partial or Zero Transfer?

Lois E. Johnson

A report submitted in Partial Fulfilment of the Requirements for the Award of Bachelor of Arts Honours, Faculty of Community Studies, Education and Social Sciences, Edith Cowan University.

October 2005.

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Skill Acquisition and Transfer to Contextually Different Tasks: Complete, Partial or Zero Transfer?

Lois E. Johnson
Abstract

There are differing opinions as to whether skills learned in one situation can be transferred and used in new situations. Anderson’s (1982, 1993) Adaptive Control of Thought theory states that complete transfer of skills from one situation to another will occur when the processes used in training are the same as those required in transfer. Logan’s (1988) Instance theory posits that complete transfer will occur only if the problems used in training are identical to those used in transfer, and that partial transfer should not occur in any transfer situation. However research by Speelman and Kirsner (2001), and Speelman, Forbes and Giesen (2004) has found that in situations where the same processes and identical problems are used, complete transfer does not necessarily occur, with partial transfer sometimes occurring in these situations. There are some criticisms to the designs of Speelman and Kirsner and Speelman et al.’s experiments, therefore more research is needed to clarify some of the issues that have been raised.

Lois E. Johnson

Dr. Craig Speelman

22nd of August, 2005
Skill Acquisition and Transfer to Contextually Different Tasks: Complete, Partial or Zero Transfer?

Skill acquisition refers to the process whereby humans learn new skills, and become faster and more efficient at performing them. Often associated with skill acquisition is the study of transfer, the extent to which skills learned in one situation can be applied or transferred to new situations (Singley & Anderson, 1989). Several theories exist as to how skill acquisition and transfer occur, with Anderson’s (1982, 1993) Adaptive Control of Thought, and Logan’s (1988) Instance theory of Automatisation being prominent theories within the field. Such theories have provided sound explanations of how skill acquisition and transfer occurs. However, as more is discovered about skill acquisition and transfer, there are suggestions that there are aspects of these theories that may require modification or updating. Before these changes are discussed however, a review is provided of the theories and research surrounding skill acquisition and transfer.

Power Law of Learning

It is widely accepted that the more an individual practices a task or skill, the faster and more accurate he or she will become at the task (Anderson, 1993). As performance of the skill speeds up, the number of mistakes is also reduced (Anderson, 1992). However there are limits to how fast an individual can perform any task. While there may be large improvements when an individual initially practices a task, the amount of improvement lessens with more practice (Fitts & Posner, 1973). A classic example of this comes from Crossman (1959), who studied workers using hand powered machines for making cigars. For approximately the first four years of employment, the performance times of workers improved quite steadily, however
after this point there was little or no extra improvement. Crossman discovered that the reason that there was no further improvement was because the machines that were used to make the cigars could not operate any faster. The workers had reached a point where their performance could not become any quicker. However this would have occurred at some point even if the machines had not had a limit, as the employees would eventually be unable to physically perform any faster. There are always limits to the amount of improvement that can be made on a task. These limits may be due to the individual not being able to physically or mentally perform any faster, or due to external influences such as the machines in the cigar making example, which were not able to operate any faster (Fitts & Posner, 1973).

The pattern of improvement and speed up in practicing a task has been shown to form a power function when plotted, as can be seen in Figure 1. This figure shows that there is large improvement on the task initially, however the amount of improvement lessens with time.

![Figure 1. Power curve demonstrating improvement on a task over time.](image)

The observation that learning curves are so frequently well described by power functions is often referred to as the Power Law of Learning (Anderson, 1995;
Newell & Rosenbloom, 1981). The formula for this power function differs slightly between researchers, but is generally accepted as $T = X + AP^b$, where $T$ refers to the time taken to perform the task, $X$ refers to the asymptote or limit of learning, and $A$ refers to the difference between performance on the first trial and the asymptotic speed, $P$ refers to the amount of practice, and $b$ is the learning rate (Anderson, 1982, 1993; Logan, 1988). Power functions are usually produced when the group data from experiments of skill acquisition are combined. Brown and Heathcote (2003) argue that when each individual's data are looked at separately, power functions are not demonstrated, and there is concern that forming a group average of the data misconstrues the effects of individual skill acquisition. However, averaging group data to form power functions is widely accepted by most researchers, including Anderson (1982, 1993) and Logan (1988), who use this method as it is an efficient way of showing whether performance time decreases over the course of an experiment.

**Anderson's ACT* Theory**

Anderson's (1982, 1993) theory of skill acquisition is known as the Adaptive Control of Thought or ACT* theory. According to Anderson (1993, 2002), cognitive performance is guided by production rules. Production rules determine the particular actions that need to be executed when an individual is faced with a certain situation, and each production rule is specific to the situation and the conditions that make up that situation (Reed, 2004). Each production rule has two parts, the first part specifying the situation that the production rule can be used in, and the second part specifying the actions that are to be carried out if faced with this situation. Production rules can therefore be thought of as having an 'IF...THEN...' form, with the 'IF'
component referring to the particular circumstance, and the 'THEN' component referring to the actions that need to be carried out (Muller, 1999; Reed, 2004).

Reed (2004, p. 342) gives the following example of a production rule:

IF the goal is to generate the plural of a noun,

THEN add an s to the noun.

Thus the IF component refers to the situation or problem that the individual is faced with, and the THEN component refers to the actions needed to solve or complete a particular problem (Reed, 2004). Often a particular situation will require several production rules, where subgoals must be achieved before reaching the final goal. A set of production rules is called a production system (Anderson, 1982). When more than one production rule could apply to a particular situation, the production rule that is more specific to the situation is used (Anderson, 1982).

When individuals are first presented with a new problem, they may need to use several production rules to form a solution. However as they practice more on the task, some of these production rules can be combined, as the individuals no longer have to go through every step. Essentially this allows individuals to skip some of the original steps, allowing them to perform the task more quickly, and this is known as rule composition (Anderson, 1992). Thus the power function speed up can be partially attributed to the fact that as skills are practiced, individuals learn to skip steps (Blessing & Anderson, 2002).

Another contributor to the speed up of skills is the strength of the productions. Anderson (1982) states that a production’s strength begins at .1, and is increased by .025 each time it is successfully applied. However when it is incorrectly applied, the strength of a production is multiplied by 0.25, so that there are more severe effects when a production rule is incorrectly applied than when it is correctly applied.
Anderson, 1982). The more a production rule is correctly used, the stronger it becomes, and stronger productions are more likely to be used than weak productions. Therefore, the number of errors individuals make is reduced with practice, as the production rules that are applied are more likely to be correct. In this way, improvement and speed up of skills can also be attributed to the strengthening of production rules (Anderson, 1993).

Logan's Instance Theory of Automatisation

According to Logan (1988), when individuals learn a new skill, they initially solve each problem or question related to that skill by using a general algorithm. After a new problem has been solved, the problem and its solution are stored in memory, and together are known as an instance. If the individual comes across the same specific problem or item at a later stage, the solution to this problem can be recalled from memory (Logan, 1988). The response to each new item is stored separately, resulting in many separate instances for the same situation. As a skill is practiced more, individuals are likely to come across situations that are the same as problems experienced earlier, and the solution for these problems can be retrieved from memory. Every time a specific problem is experienced, a new instance for that problem will be stored in memory. When individuals are faced with a problem that is the same as one they have confronted before, an instance starts to be retrieved from memory, while at the same time the general algorithm also starts to determine a solution. Whichever produces the answer first is used. However the more times an individual experiences a specific problem, the more instances there are stored in memory for that problem, and if there are many stored instances for a specific problem it will be more likely that one of these instances will be retrieved more
quickly than the general algorithm can determine an answer. Logan attributes the speed up of performance to the race between algorithms and instances retrieved from memory, as while the general algorithm always takes the same amount of time to finish, instances are retrieved more and more quickly each time. Logan also states that automatic performance of a skill occurs as general algorithms are used less and use of memory based solutions becomes more frequent. Eventually, only use of memory is required, as retrieving an instance will ultimately become quicker than using the algorithm, and it is at this point that a skill can be regarded as automatic. In essence, automatic performance uses memory, whereas non-automatic performance uses general algorithms.

Transfer of skills to new situations

The skill acquisition theories of Anderson (1982, 1993) and Logan (1988), also have theories about transfer. Transfer refers to the extent to which skills learned in one situation can be transferred or applied to new situations (Singley & Anderson, 1989). When examining transfer, two phases are generally used, namely a training phase and a transfer phase. The individual is presented with a particular set of problems in the training phase, and is then given another set of problems in the transfer phase, and the ability of individuals to apply skills learned in the training phase to these new problems is then assessed (Anderson, 1982; Logan, 1988). The power law of learning is a useful way of demonstrating the amount of transfer that occurs, and researchers will often plot the group scores for each block of training and transfer, in order to more clearly demonstrate whether a disruption between training and transfer occurred. There are three main types of transfer, the first being complete transfer, where skills learned for one situation can be completely transferred to the
new situation, allowing the individual to keep performing at the same rate. Complete transfer means that despite the change in situation, the speed that the individual performs the task at is not affected or slowed down (Speelman & Kirsner, 1997). A power function demonstrating complete transfer would look similar to the power function in Figure 1, in that there is no disruption in performance time between training and transfer. The second type of transfer is partial transfer, where performance speed is faster than it would have been had the individual received no prior experience of the task, but slower than performance prior to the change in task. Finally there is zero transfer, where performance speed is slowed down to the same speed that would have occurred before the task was practiced at all (Speelman & Kirsner, 1997). A power function showing zero transfer would appear as though the function had started again in the transfer phase, in that the performance time in the transfer phase would be as if there had been no practice on the task at all. In essence, complete transfer means that the skills learned in the first task are applicable to the transfer task, in partial transfer the skills are somewhat relevant, and in zero transfer the skills are not at all applicable.

According to Logan (1988), transfer is item specific, in that transfer will only occur on items that have been experienced before, so the items or problems in the new situation must be identical to those used in the first situation. Therefore, if in the transfer phase the individual is presented with different problems than in the training phase, then no transfer will occur, and the individual will perform as if he or she had not received any prior practice on the task (Logan, 1988). According to Logan, if the transfer task uses the exact same questions as in the training task, then transfer will be complete. If the transfer task uses different questions to the training task, then transfer
will be zero. According to Logan, partial transfer will not occur (Speelman & Kirsner, 1997).

An example of what occurs when participants attempt to apply old skills to new problems comes from Logan and Klapp (1991). Logan and Klapp created a number of problems of the form \( A + 3 = D \). Participants were asked to verify whether the equations were true or false by counting forward through the alphabet. For instance, in the given example this would involve determining if \( D \) comes three letters after \( A \) in the alphabet. Participants initially reported solving the problems by counting, which was a slow process that Logan and Klapp believed required use of a general algorithm. However with more practice participants began to solve the problems by memory, in that they recalled their previous answers to the same questions in order to determine their answer, rather than by counting forward through the alphabet. In the first session of training participants reported using counting strategies to solve the problems 93% of the time, however by the final training session participants reported using counting to solve only 28% of the problems. Logan and Klapp stated that this indicates a change between use of the general algorithm to use of instances. During training, participants were given problems using only one half of the alphabet, however in the transfer phase participants were exposed to problems using the other half of the alphabet. Essentially the task was the same, but the questions were different and the participants had not experienced them before. During the transfer phase, the amount of time participants took to solve each of the problems increased significantly, and participants reported returning to counting strategies for 85% of the problems (Logan & Klapp, 1991). This supports Logan’s notion that transfer is item specific, as items that had not been experienced before took much
longer to be solved, and participants had to use old strategies in order to determine their answers.

According to Anderson's (1982, 1993) ACT* model, the extent of transfer depends on the amount of similar productions between the two tasks. If the transfer task can be performed with similar productions to the training task, then complete transfer is possible. If there are very few similar productions between training and transfer tasks, then zero transfer is more likely. Anderson's theory states that partial transfer can occur, such as in a situation where some but not all of the production rules required to perform the transfer task were developed in the training task (Speelman & Kirsner, 1997). Transfer in the ACT* theory is different to the Instance theory, because production rules are not specific like instances are. While instances are applicable to only one situation, production rules are more flexible and can be applied to different situations (Logan, 1988; Speelman & Kirsner, 1997).

Research by Speelman and Kirsner (1997) supports Anderson’s (1982, 1993) theory that the amount of transfer to a new task will depend on the amount of shared productions between training and transfer. Speelman and Kirsner taught participants to solve syllogisms in two different forms, with an example of one of these forms being: “All of the acrobats are butchers. All of the butchers are cricketers. Therefore all of the acrobats are cricketers” (Speelman and Kirsner, 1997, p. 93). After becoming efficient at the task participants began the training phase, where they were asked to verify whether presented syllogisms were true or false. During training 288 syllogisms were presented, and in transfer 96 new syllogisms were presented. The syllogisms presented in transfer had not been experienced before by the participants, however they were of the same two forms as those presented in training. Speelman and Kirsner conceived that for such a task, Anderson would predict that transfer
should occur, as despite the transfer tasks being new the form of the syllogisms were the same, thus the processes required to solve them were the same as in training. Therefore there were common productions between training and transfer. Results of the study showed that partial transfer occurred in some conditions, and complete transfer occurred in other conditions. The fact that transfer occurred indicates that the skills or processes used in training were able to be applied to the new syllogisms presented in transfer, indicating that there were common productions between the two tasks. Speelman and Kirsner's research shows support for Anderson's predictions that transfer depends on the number of shared productions between tasks in training and transfer.

*Suggestions for the modification of Anderson and Logan's theories*

Palmeri (1997) states that Logan’s (1988) Instance theory is a credible model in its reasoning of how automaticity develops, and that it provides a sound explanation of many aspects of skill acquisition, particularly why there is often little transfer of skills in tasks where new objects are presented in the transfer task. Palmeri has supported Logan’s Instance theory through his own work, for example Palmeri’s research has supported Logan’s theory that there is a change from use of algorithms to the use of examples from memory when an individual learns a new skill (Johansen & Palmeri, 2002). However Palmeri has also argued that there are limitations to Logan’s Instance theory, such as the notion that memory retrieval rather than the use of algorithms will only occur if questions presented within the transfer task are exactly identical to questions presented in the training task. Palmeri argues that retrieval of items from memory can also occur for items that are similar, but not identical, to items that have been experienced before.
Another aspect of the Instance theory that Palmeri (1997) disagrees with is the notion that only the first instance that is retrieved from memory is used. Palmeri argues that when an individual is presented with an item that is similar to examples stored in memory, these examples are also recalled. The more similar the examples are to the item, the faster they are retrieved. In this way, more than one response is available, and possible responses compete until the best solution is chosen. The theory that similar though not identical instances can be retrieved from memory is important, as it posits an explanation of why partial transfer sometimes occurs, even when Logan (1988) stated that only complete or zero transfer was possible. Essentially, Palmeri accepts that Logan’s Instance theory is valid, however he believes that there are limitations to this theory, and thus his work focuses on what he believes is the further expansion and correction of Logan’s theory.

Anderson (1982, 1993) and Logan (1988) each have particular theories about transfer, however recent research has produced results counter to those theorised by Anderson and Logan, particularly in regards to transfer of skills. Specifically, partial transfer has been shown to occur in situations where Anderson and Logan would have predicted complete transfer. Speelman and Kirsner (2001) investigated whether the extent of transfer could be predicted by a participant’s performance during the training stage. The training task within their experiment involved solving three different equations, and the transfer task used these exact same equations, as well as two new equations. The first three equations were identical in training and transfer, and so the processes required to solve these first three equations were exactly the same in training and transfer. The additional two equations were based on aspects of the first three equations, so that the processes required to solve the equations did not differ greatly to those used in the training phase. According to Anderson (1982,
1993), a situation such as this should result in complete transfer, as the processes used in training and transfer were exactly the same. However the experiment showed that upon beginning the transfer phase, performance times of the experimental group on the first three equations of each trial slowed for a period of time, rather than continuing to improve. Despite the fact that the same processes were required to solve these three equations in both the training and transfer phases, there was still a disruption in performance time, indicating that the inclusion of two additional equations was enough to slow performance times on the original three equations. Although performance time soon improved again, this disruption in performance should not have occurred according to Anderson’s theory (Speelman & Kirsner, 2001).

Speelman and Kirsner’s (2001) study appeared to demonstrate that there were discrepancies between what Anderson (1982, 1993) theorised would occur during transfer, and what actually occurred. However the possibility that there were other factors that may have caused the change in performance time first had to be considered. When considering other possible reasons for the change in performance times, Speelman, Forbes and Giesen (2004) contemplated that a change in the visual context between training and transfer phases could have been responsible for the increase in performance time. As the training phase used three equations, and the transfer phase used five equations, the two phases were different in their appearance. Speelman et al. concluded that this may have affected the conceptual context of the task, leading participants to believe that the transfer task was different or more difficult to the training task. This could have potentially caused the change in performance time.
In order to eliminate the possibility that the change in the visual appearance or apparent complexity of the task could have caused the disruption in performance time, Speelman et al. (2004) ran an experiment where tasks for both the training and transfer stages were visually the same. The training task of the experiment involved the participant answering questions from the six times table, for example in the form of 6x2 = _. The transfer task included the exact same problems that were used in the training task, however additional distractor problems were also added, in forms such as 6x_ = 12, or 12÷6=_. Each problem was presented separately, so that there was never more than one problem presented on the screen at any given time. In this way, the visual appearance of the training task was the same as in the transfer task, unlike in Speelman and Kirsner’s (2001) study, where there were more tasks per screen in the transfer phase than in the training phase. In this way, if a change in performance time was found on the target problems (e.g., 6x2 = _), it could be that this change was caused by contextual differences rather than visual differences (Speelman et al., 2004). Speelman et al.’s study was designed in such a way that both Anderson’s (1982, 1993) and Logan’s (1988) theories about transfer could be tested. As the same processes were used in training and transfer, Anderson would predict that complete transfer would occur in this situation. Logan would also predict that complete transfer would occur for the items already encountered in training, as these items were exactly the same in training and transfer, and the solutions would thus be retrieved from memory rather than having to be solved using the general algorithm (Speelman et al., 2004).

Speelman et al.’s (2004) experiment showed a disruption in performance time between the end of the training phase and the beginning of the transfer phase for target problems. Due to the appearance of the experiment, it was known that change
in visual context was not responsible for this disruption. Thus, it was presumed that differences between phases were a result of the change in context. Despite the fact that the participants had already experienced all of the target problems in the training phase, there was still a disruption, indicating that simply adding new problems was enough to cause the participants to become slower in their performance times, even on questions that they had previously experienced (Speelman et al., 2004).

Results of the study by Speelman et al. (2004) contradict the assumptions of Anderson (1982, 1993) and Logan (1988), who would have predicted that in such a situation, complete transfer should occur. However, reviewers raised some objections in regards to the design of Speelman et al.’s experiment. These objections focused on the fact that the tasks used within the transfer phase of the experiment were not equally spaced. For example, in the training phase, each target problem was presented one after the other. In the transfer phase however, the target problems were dispersed randomly among the distractor problems. This resulted in longer periods of time on average between performing each target task in the transfer phase, as compared to in the training phase. The amount of time it takes an individual to solve a problem will depend on how long it takes for them to retrieve the necessary information for the task from memory, and the longer that information is stored within memory without being used, the more it is likely to decay (Frensch & Geary, 1993). In this way, the reviewers suggested that the disruption in performance times between training and transfer may have been due to memory decay rather than the change in tasks, because of the longer amount of time between the presentation of each target problem in the transfer phase. Therefore, Speelman et al.’s results could not be seen as conclusive, due to the possibility that there were other explanations for the results.
Studies conducted by researchers such as Speelman and Kirsner (2001), and Speelman et al. (2004) have produced results that conflict with the predictions of Anderson (1982, 1993) and Logan (1988) about what will occur in particular transfer situations. However, the designs of these studies have been such that there are other possible explanations for the results. This has left a gap in the current literature for a study on skill acquisition that controls for visual differences between training and transfer phases, while keeping equal spacing between target items. Such research would help clarify whether a change of context can affect performance, and whether partial transfer can occur even on tasks where the processes that are used are identical in training and transfer, in contrast to Anderson (1982, 1993) and Logan’s (1988) theories that predict complete transfer should occur.
References


Skill Acquisition and Transfer to Contextually Different Tasks: Complete, Partial or Zero Transfer?

Lois E. Johnson
Abstract
The current experiment investigated the skill acquisition theories of J. R. Anderson (1982, 1993) and G. D. Logan (1988), that predict that complete transfer will occur when the same problems are used in training and transfer. The study tested 61 participants on a computer task involving target problems in the form of six times table questions, and distractor problems in the form of addition or subtraction questions. While target problems were the same in training and transfer phases, distractor tasks differed between phases. It was hypothesised that changing the distractor problems would disrupt performance on the target problems, causing partial rather than complete transfer. Results confirmed the hypothesis, performance on target problems was significantly disrupted ($p < .01$) when the context of the task changed. The study has implications for the theories of Anderson and Logan, suggesting that such theories may benefit from amendment to allow for the effect that context can have on the transfer of skills.

Lois E. Johnson
Dr. Craig Speelman
October 31st, 2005.
Introduction

Skill acquisition refers to the way that individuals learn new skills, and become faster and more efficient at performing these skills with practice. The study of transfer is often associated with skill acquisition, and refers to the extent to which skills learned in one situation can be applied or transferred to new situations (Singley & Anderson, 1989). Anderson’s (1982, 1993) Adaptive Control of Thought theory, and Logan’s (1988) Instance theory of Automatisation, are prominent theories of skill acquisition and transfer. These theories have provided sound explanations for how skill acquisition and transfer occurs. However, as more is discovered about skill acquisition and transfer, there are suggestions that there are aspects of these theories that may require modification or updating. Specifically, such theories predict that skills will be completely transferred to new situations as long as the processes required in the new situation are the same as those used in the first situation. Yet other research has demonstrated that even if the exact same processes are required in training and transfer, complete transfer will not always occur. It appears that other factors, such as context, can affect the transfer of skills to new situations. The current study was performed in order to examine this effect. Before describing the experiment a review of the theories and research surrounding skill acquisition and transfer is provided, followed by a discussion of the effect of context on transfer.

Power Law of Learning

When individuals initially practice a task, there are usually large improvements in performance speed at first, however the amount of improvement is reduced with more practice (Fitts & Posner, 1973). The plotted reaction times of
individuals practicing new tasks has the same form as a power function, an example of which is shown in Figure 1.

![Graph showing the relationship between reaction time and amount of practice](image)

**Figure 1.** Power function demonstrating improvement on a task over time.

As Figure 1 suggests, the time to perform a task may initially be quite long, however performance time usually improves quite steadily with practice. Eventually the curve of the function begins to flatten, indicating that the individuals performing the task are nearing a point where any more improvement they can make on the task will be minimal. The fact that most learning curves can be described by power functions is often referred to as the Power Law of Learning (Anderson, 1995; Newell & Rosenbloom, 1981). The general formula for the Power Law of Learning differs slightly between researchers, but is generally accepted as $T = a + bP^c$, where $T$ refers to the time taken to perform the task, $a$ refers to the asymptote or limit of learning, and $b$ refers to the difference between performance on the first trial and the asymptotic speed, $P$ refers to the amount of practice, and $c$ is the learning rate (Anderson, 1982, 1993; Logan, 1988). The Power Law of Learning is widely accepted as a fundamental feature of skill acquisition by many researchers, including
Anderson (1982, 1993) and Logan (1988), whose popular theories of skill acquisition have the Power Law as a central element.

**Anderson's ACT* Theory**

Anderson's (1982, 1993) theory of skill acquisition is known as the Adaptive Control of Thought (ACT*) theory. Anderson (1993, 2002) theorised that cognitive performance is guided by production rules, which determine the actions that need to be executed when an individual is faced with a certain situation. Each production rule is specific to the situation and the conditions that make up that situation (Reed, 2004). Production rules have an ‘IF...THEN...’ form, in that each production rule consists of two parts. The ‘IF’ component specifies the situation that the production rule can be used in, and the ‘THEN’ component specifies the actions that need to be carried out if faced with this situation (Muller, 1999; Reed, 2004).

When individuals are first presented with a new problem, they may need to use several production rules to form a solution. This process can make solving the initial problem quite slow. However, as individuals practice more on the task, some of these production rules can be combined, in that the individuals no longer have to go through every step. This process, known as rule composition, allows individuals to skip some of the original steps needed to solve a problem, thus allowing them to perform the task more quickly (Anderson, 1992). The power function speed up can be partially attributed to the fact that as skills are practiced, individuals learn to skip steps (Blessing & Anderson, 2002). Another contributor to the speed up of skills is the strength of the productions. Anderson (1982) states that the strength of a production increases each time it is successfully applied. Productions that are incorrectly applied decrease in strength, and are less likely to be used for a similar problem (Anderson,
1982). The more a production rule is correctly used, the stronger it becomes, and stronger productions are more likely to be used than weak productions. Therefore, the amount of errors individuals make is reduced with practice, as the production rules that are applied are more likely to be correct. In this way, improvement and speed up of skills can also be attributed to the strengthening of production rules (Anderson, 1993).

Logan's Instance Theory of Automatisation

According to Logan (1988), when individuals learn a new skill, they initially solve each problem or question related to that skill by using a general algorithm, a basic formula that can be applied in solving problems. When a new problem has been solved, the problem and its solution are stored in memory, and together are known as an instance. If the individual comes across the exact same problem or item at a later stage, the solution to this specific problem can be recalled from memory and applied to the problem (Logan, 1988). The application of this solution to the situation is also stored in memory, as a new and separate instance. In this way, if the same situation is experienced a number of times, then there will be a number of separate instances stored for the same situation. When individuals are faced with a problem that is the same as one they have confronted before, an instance starts to be retrieved from memory, while at the same time the general algorithm also starts to determine a solution, and whichever produces the answer first is used. However if there are many stored instances for a specific problem it will be more likely that one of these instances will be retrieved more quickly than the general algorithm can determine an answer. Logan attributes the speed up of performance to the race between algorithms and instances retrieved from memory, because while the general algorithm always
takes the same amount of time to finish, instances are retrieved more and more quickly each time, as there are more to choose from.

Transfer of skills to new situations

Both Anderson (1982, 1993) and Logan (1988) also have theories about transfer. When examining transfer, two phases are generally used, namely a training phase and a transfer phase. The individual is presented with a particular set of problems in the training phase, and is then given another set of problems in the transfer phase. The ability of individuals to apply skills learned in the training phase to these new problems is then assessed (Anderson, 1982; Logan, 1988). There are three main types of transfer, the first being complete transfer, where skills learned in one situation can be completely transferred to the new situation, allowing the individual to keep performing at the same rate without their performance being affected or slowed down (Speelman & Kirsner, 1997). The second type of transfer is partial transfer, where performance speed is faster than it would have been had the individual received no prior experience of the task, but slower than performance prior to the change in task. Thirdly there is zero transfer, where performance speed on the transfer task is at the same speed that would have occurred before the task was practiced at all (Speelman & Kirsner, 1997). In essence, complete transfer means that the skills learned in the first task are applicable to the transfer task, in partial transfer the skills are somewhat relevant, and in zero transfer the skills are not at all applicable.

According to Logan (1988), transfer is item specific, in that transfer will only occur if the items or problems in the new situation are identical to those used in the first situation. No transfer will occur if the individual is presented with different
problems in the training and transfer phases. Logan claims that transfer can only be complete or zero; partial transfer will not occur (Speelman & Kirsner, 1997). According to Anderson (1982, 1993), the extent of transfer will depend on the amount of similar productions between the two tasks. If the transfer task can be performed with similar productions to the training task, then complete transfer can occur. If there are no similar productions between training and transfer tasks, then zero transfer is more likely. According to Anderson, partial transfer can occur, for example in a transfer situation where only some of the production rules used in transfer were acquired during training (Speelman & Kirsner, 1997). Production rules are not specific like instances are, so while instances are applicable to only one situation, production rules are more flexible and may be applied to different situations (Logan, 1988; Speelman & Kirsner, 1997).

Suggestions for the modification of Anderson and Logan’s theories

Logan’s (1988) Instance theory, and Anderson’s (1982, 1993) ACT* theory, have had support from different researchers, such as Palmeri (1997), whose research has demonstrated support for Logan’s theories, as well as Speelman and Kirsner (2001), who have supported some of Anderson’s claims. However such researchers have also discovered that there are areas of Logan and Anderson’s theories that could benefit from some revision, for as more research is carried out, it appears that there are some conflicts between the theories and data. For example, Speelman and Kirsner have demonstrated that transfer can occur even in situations where items that have not been previously experienced are presented in transfer. Such research questions Logan’s notion that transfer can only occur if identical items are used in training and transfer. Palmeri likewise argues that retrieval of items from memory can also occur
for items that are similar, but not identical, to items that have been experienced before.

Research by Speelman and Kirsner (2001), and Speelman, Forbes and Giesen (2004) has demonstrated that partial transfer can occur in situations where Anderson (1982, 1993) and Logan (1988) would have predicted complete transfer. Each trial of the training task in Speelman and Kirsner’s experiment involved asking participants to use three different equations to solve some problems. Each trial of the transfer task of the experiment asked participants to use five equations to solve some problems. Three of the five equations were exactly the same as in transfer, and two equations were new. Since the first three equations were identical in training and transfer, the processes required to solve these first three equations should have been the same in training and transfer. The additional two equations used similar processes to the first three equations, so that the processes required to solve the equations in transfer did not differ greatly to those used in the training phase. According to Anderson, in a situation such as this, performance on the three equations common to the two phases would result in complete transfer, as the same processes were required in training and transfer. Contrary to these expectations however, the experiment showed that upon beginning the transfer phase, performance times on the first three equations slowed for a period of time, rather than continuing to improve. Despite the fact that the same processes were required to solve these three equations in both the training and transfer phases, there was still a disruption in performance time, indicating that the inclusion of two additional equations caused performance times to slow on the original three equations. Although performance time soon improved again, this disruption in performance should not have occurred, according to Anderson’s ACT* theory (Speelman & Kirsner, 2001).
Speelman and Kirsner's (2001) study appeared to demonstrate that there were discrepancies between what Anderson (1982, 1993) theorised would occur during transfer, and what actually occurred. However the possibility that there were other factors that may have caused the change in performance time first had to be considered. When considering other possible reasons for the change in performance times, Speelman et al. (2004) contemplated that a change in the visual context between training and transfer phases could have been responsible for the increase in performance time. As the training phase used three equations, and the transfer phase used five equations, the two phases were different in their appearance. Speelman et al. concluded that this may have affected the conceptual context of the task, leading participants to believe that the transfer task was more difficult than the training task. This could have potentially caused the change in performance time.

In order to eliminate the possibility that the change in the visual appearance or apparent complexity of the task could have caused the disruption in performance time, Speelman et al. (2004) conducted an experiment where tasks for both the training and transfer stages were visually the same. The training task of the experiment involved the participants answering questions from the six times table (e.g., 6x2 = _). The transfer task included the exact same problems that were used in the training task, however additional distractor problems were also added, in forms such as 6x_ = 12, or 12+6=_. Each problem was presented separately, so that there was never more than one problem presented on the screen at any given time. In this way, the visual appearance of the training task was the same as in the transfer task, unlike in Speelman and Kirsner's (2001) study, where there were more problems per screen in the transfer phase than in the training phase. In this way, if a change in performance time was found on the target problems (e.g., 6x2 = _), it could be that this change
was caused by contextual differences rather than visual differences (Speelman et al., 2004). Speelman et al.'s study was designed in such a way that both Anderson's (1982, 1993) and Logan's (1988) theories about transfer could be tested. As the same target problems were presented in both phases, the same processes should be used in training and transfer, and so Anderson would predict that complete transfer would occur in this situation. Logan would also predict that complete transfer would occur for the items already encountered in training, as these items were exactly the same in training and transfer, and the solutions would thus be retrieved from memory rather than having to be solved using the general algorithm (Speelman et al., 2004).

Speelman et al.'s (2004) experiment showed a disruption in performance time between the end of the training phase and the beginning of the transfer phase for target problems. Due to the appearance of the experiment, it was known that change in visual context was not responsible for this disruption. Thus, it was presumed that differences between phases were a result of the change in context. Despite the fact that the participants had already experienced all of the target problems in the training phase, there was still a disruption, indicating that simply adding new problems was enough to cause the participants to become slower in their performance times, even on questions that they had previously experienced (Speelman et al., 2004).

While results of the study by Speelman et al. (2004) contradict the assumptions of Anderson (1982, 1993) and Logan (1988), that complete transfer should occur, some objections in regards to the design of Speelman et al.'s experiment were raised by reviewers. These objections focused on the fact that the problems used within the transfer phase of the experiment were not equally spaced. For example, in the training phase, each target problem was presented one after the other. In the transfer phase however, the target problems were dispersed randomly.
among the distractor problems. This resulted in longer periods of time on average between performing each target problem in the transfer phase, as compared to in the training phase. It was suggested that the necessary information might decay from memory during this time, leading to slower performance times in the transfer phase.

To resolve this issue, the current experiment was performed, which controlled for visual differences between training and transfer phases, while keeping equal spacing between target items. This experiment was designed to clarify whether a change of context can affect performance, and whether partial transfer can occur even on tasks where the processes that are used are identical in training and transfer, in contrast to Anderson (1982, 1993) and Logan's (1988) theories that predict that complete transfer should occur.

The current study built upon the experimental design of Speelman et al. (2004). Its aim was to investigate whether contextual change can affect the performance speed of individuals, and specifically whether partial transfer can occur in situations where identical processes are used in training and transfer. The experiment presented participants with target problems that were the same in training and transfer, as well as distractor problems in both training and transfer. By doing this, it could be investigated whether a change in distractor problems was capable of causing a disruption in performance on target problems, resulting in partial rather than complete transfer.

Method

Participants

A total of 61 participants were tested for the current experiment. Thirty-four of the participants were recruited from the Edith Cowan University School of
Psychology registry of volunteers, and 27 were members of the general public. The data from one participant was discarded as they did not achieve the minimum accuracy rate of 80% on target trials for their total performance on the experiment. The minimum age to participate was 17 years, and the age of participants ranged from 17 to 59 years. One participant would not specify her age, consequently aside from this participant’s age, the mean age of the participants was 25.53 years. Of the participants, 36 were females ($M = 24.86$ years, $SD = 9.862$), and 24 were male ($M = 26.54$ years, $SD = 11.591$). As an incentive for participating, participants who were recruited through the School of Psychology registry were offered a raffle ticket to go into a draw to win $50.

**Materials and Procedure**

This study was granted approval by the Edith Cowan University Human Research Ethics Committee.

A Macintosh G3 computer, programmed with SuperLab Pro Version 1.74, was used to present the task and record participant responses. Participants performed the task alone in a quiet room, and the researcher was nearby should the participant need assistance. The task took approximately 15 to 20 minutes for participants to complete, and included in this time were practice trials that used different questions to the actual experiment.

The experiment consisted of two phases, a training phase and a transfer phase. A total of 144 trials were presented, with 72 trials presented in the training phase, and 72 trials presented in the transfer phase. Each trial consisted of two parts, the first part was a target problem, the second part was a distractor problem, and each of these two parts was presented separately. For the first part, or target component, of each trial, participants were presented with the target question, which was a six times table
problem. In keeping with problems used in Speelman et al.'s (2004) study, six target problems were used, namely 6 x 2, 6 x 3, 6 x 4, 6 x 7, 6 x 8, and 6 x 9. Participants were presented with one of these questions in the centre of the computer screen. They were asked to think about their answer, and then press the space bar. Following this, two possible answers, one correct and one incorrect, were presented in the bottom left and right corners of the screen. The participants were asked to select the correct answer, by using the 'z' key to select the answer on the left of the screen, and the '/\' key to select the answer on the right of the screen. These two keys were labelled with brightly coloured stickers, a different colour for each key, in order to make finding these keys easier. Participants received feedback on their response; either 'Correct' or 'Incorrect' would be displayed on the screen.

For the second part, or distractor component, of each trial, participants were asked to remember the correct answer to the first part of the trial, and were asked to apply it to the second part of the trial, by either adding or subtracting a particular number from their answer. For example a participant might be asked to add or subtract 2, 3, 4, 5, 6, or 7 to or from the solution to the target part of the trial. Once participants had determined their answer, they pressed the space bar. Again, two possible answers appeared on the bottom left and right corners of the screen, one correct and one incorrect. The participants selected the correct answer, again using the 'z' and '/\' keys, and a new screen would inform them whether they were correct or incorrect. After pressing the space bar again, a new trial would begin.

The target problems were always presented in the first part of each trial, both for the training and transfer phases. The exact same target questions were used in both the training and transfer phases. However the distractor problems, presented in the second part of each trial, were different in training and transfer. Six distractor
problems were used in training, and six different distractor problems were used in transfer. If a participant was presented with addition questions in the training phase, then in the transfer phase they would be presented with subtraction problems. The opposite could also occur, in that a participant would be presented with subtraction problems in the training phase, and then addition problems in the transfer phase. The visual appearance of the problems presented on the screens however was the same in training and transfer, only one question was presented at a time, and they were always presented in the centre of the screen. Likewise, the possible answers that were presented were always presented in the bottom right and left hand corners of the screen. For counterbalancing purposes, two different versions of the task were created, with half the participants randomly assigned to one version, and the other half randomly assigned to the second version. In Version 1, each trial of the training phase consisted of a target problem followed by an addition problem. For the transfer phase of Version 1, each trial consisted of a target problem followed by a subtraction problem. In Version 2, each trial of the training phase consisted of a target problem followed by a subtraction problem, and in the transfer phase each trial consisted of a target problem followed by an addition problem. Creating two opposite versions ensured that the data would not be biased in the event that participants found either the addition or subtraction problems easier.

A total of 24 blocks of trials were used in the experiment, with 12 blocks for the training phase and 12 blocks for the transfer phase. As there were six trials in each block, and there were six target problems in total, each of these target problems was presented once in each block, and the order of presentation was random. There were also six distractor problems presented in each block. In the training phase of Version 1, participants were asked to add 2, 3, 4, 5, 6, or 7 to their answers. Each of these
addition problems was presented once in each block, and the order was random. In the
transfer phase of Version 1, participants were asked to subtract 2, 3, 4, 5, 6, or 7 from
their answer. Again, each of these subtraction problems was presented once in each
block in random order. In Version 2, participants were presented with the subtraction
problems in training, and the addition problems in transfer. The pairing of target and
distractor problems was always random. In Block 1 a participant might be presented
with the target problem '6 x 2 = _' followed by the distractor task 'Add 4 to your
answer.' In subsequent blocks, this particular distractor task could be paired with any
other target task, and did not always follow the 6 x 2 problem. Positioning of answers
was also equally distributed, in that for each block the correct answer was presented
on the left hand side of the screen for half of the trials, and on the right hand of the
screen for the other half of the trials. Also, as both a correct and an incorrect answer
was presented on screens where participants were asked to choose an answer, for half
of the trials the incorrect answer presented was higher than the correct answer, and for
the other half of the trials the incorrect answer was lower than the correct answer.

Within the experiment, the independent variable was phase of the experiment,
namely training or transfer. The dependent variable was reaction time in milliseconds.
The reaction times of participants in responding to each trial was recorded by
SuperLab Pro.

Results

From each participant's data, only the reaction times from correctly answered
target problems were used in the analysis. For each participant an average
performance time was calculated for the target problems for each block, and an
accuracy percentage for each block was also calculated. An average reaction time was
calculated for each block, in that reaction times from all the participants for one block, for example Block 1, were summed and averaged in order to determine an overall average reaction time for that block. An average was found for each of the 24 blocks, and these 24 averages were then plotted in order to determine whether a power function of the form $RT = a + b \times P^c$ provided a good fit to the data. Parameters of the best fit power function were determined, and are presented in Table 1.

Table 1

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>c</th>
<th>$R^2$</th>
<th>rmsd</th>
</tr>
</thead>
<tbody>
<tr>
<td>1680.89</td>
<td>2339.09</td>
<td>-0.72</td>
<td>.99</td>
<td>64.75</td>
</tr>
</tbody>
</table>

*Note: rmsd = root mean squared deviation.*

When the data was initially plotted, a large outlier was found within Block 16. When examining the data it was found that a participant had taken 50 seconds to respond to a target trial, which was considerably longer than typical response times. Consequently this outlier was deleted from the data set.

The best-fit power function was fitted to the training data, and was extrapolated 12 blocks into the transfer phase. Figure 2 shows the average reaction times for each block, as well as the best-fit power function. As can be seen, the scores fit a power function quite well. This is supported by the large $R^2$ value and small rmsd value (Table 1). It can also be seen that there appears to be a disruption between Block 12 and Block 13.

The best fit power function, as seen in Figure 2, is a useful way of predicting performance in the transfer phase had there been no disruption. As can be seen in
Figure 2, the 95% confidence intervals of the transfer data overlap with these predicted values for all but the first block of transfer. This further demonstrates that there was a disruption to performance at the beginning transfer, when the distractor problems changed.

Figure 2. Plotted average reaction times for each block of trials.

In order to determine whether the disruption between blocks 12 and 13 was significant, a paired samples t-test was performed. The results show that Block 12 ($M = 2141.70$ ms, $SD = 871.11$ ms) was significantly faster than Block 13 ($M = 2467.90$ ms, $SD = 905.98$ ms), $t(59) = 4.23$, $p < .01$. This demonstrates that there was a significant slowing of performance with the transition from the training phase to the transfer phase.
Discussion

The results of the current experiment contradict the transfer theories of Anderson’s (1982, 1993) Adaptive Control of Thought theory, and Logan’s (1988) Instance theory of Automatisation. Anderson theorised that complete transfer would occur if the same processes used in training could be applied to the problems presented in transfer. Likewise, Logan theorised that transfer would only occur if the participants experienced the same problems in training and transfer, and that only complete or zero transfer could occur. Thus in the present study, as the exact same problems were presented in training and in transfer, both Anderson and Logan would predict that complete transfer should occur for the target problems.

Figure 2 demonstrates that the reaction times on target problems follows a fairly uniform power function until the end of the training phase, where there is a significant disruption in performance. After this disruption, reaction times have returned to their previous speed by Block 14, and the power function has continued. As the disruption between Block 12 and Block 13 is significant, this indicates that partial transfer has occurred, as reaction times at the beginning of transfer are not as slow as they were at the beginning at training, yet are still significantly slower than they were at the end of training. Despite Anderson (1982, 1993) and Logan’s (1988) predictions that complete transfer would occur if the same problems were used in both phases, and Logan’s claim that only zero or complete transfer could occur, it can be seen that partial transfer has occurred in the current experiment. This finding shows that complete transfer will not necessarily occur, even when the processes used in training are the same as those required in transfer.

A criticism of Speelman and Kirsner’s (2001) study was that the visual appearance of problems was not the same in training and transfer, in that in transfer,
more questions were presented per screen than in training. It was suggested that this visual change might have been responsible for the disruption in performance rather than change in context, as participants may have perceived the task as being more difficult. The current experiment improved the design of Speelman and Kirsner’s study, by assuring that the visual appearance of problems was the same in both training and transfer, in that only one problem was presented on each screen at a time, and the visual appearance of the problems was the same throughout the experiment. Consequently, the possibility that a change in visual appearance caused confusion and thus an increase in performance time, can be eliminated for this study.

A criticism of Speelman et al.’s (2004) study was that the spacing between target problems was unequal. While in the training phase the target problems were presented one after the other, in the transfer phase the target problems were interspersed with distractor problems. In this way, there were longer periods of time between target problems in the transfer phase than in the training phase. Thus it was suggested that the representations for solving the target problems might decay from memory during this time, and that this could have been responsible for the disruption in performance, rather than the change in context as was suggested by Speelman et al.

In the current experiment there was equal spacing between the presentation of problems, in that each target problem was always followed by a distractor problem, both in training and in transfer, and this was an improvement on Speelman et al.’s (2004) design. However while this makes the training and transfer phases the same in terms of spacing, it might still be suggested that by changing the distractor problems at the beginning of transfer, participants would need more time to solve these new distractor problems than they would need to solve the distractor problems they had already experienced. The longer participants spent solving distractor problems, the
longer they would be away from the target problems. Thus it could be suggested that spending longer amounts of time away from the target problems might in turn might cause some amount of memory decay, and that this could be a possible cause for the disruption, and not context as has been assumed.

While this is a possible criticism, it is important to consider how much time participants in Speelman et al.'s (2004) study spent on distractor problems, compared to how much time participants in the current study spent on distractor problems. In Speelman et al.'s study, all of the distractor problems could be considered as being as difficult or more difficult than the target problems themselves. For example, an illustration of a target problem used in Speelman et al.'s is $6 \times 2 = \_$. Examples of distractor problems that were used are $6 \times \_ = 12$, $12 \div 6 = \_$, $10 + 38 = \_$, and $6 \times 26 = \_$. In this way, each distractor problem would have required the same amount of time or perhaps longer to solve than the target problems. This would result in long periods of time away from the target problems, particularly as in Speelman et al.'s study a participant might receive several distractor problems in a row before returning to a target problem. In this way, Speelman et al.'s study differs to the current study, as in this study distractor problems were basic and could be solved quickly, often in only one or two seconds. Due to the fact that the amount of time spent away from target problems was usually only a few seconds, it is unlikely that the stored information for solving the target problems would have decayed in such a short space of time.

The current experiment improved upon the design of Speelman and Kirsner (2001), in that the visual appearance of tasks was made uniform in both training and transfer. It also improved upon the design of Speelman et al. (2004) in that the spacing of target and distractor trials was equal in training and in transfer. While both Speelman and Kirsner, and Speelman et al.'s studies demonstrated that partial transfer
occurred, it was these confounding factors that impaired the conclusiveness of their finding that the partial transfer was caused by contextual change. As the confounding factors of visual appearance and spacing were controlled for in the present study, it is thus most likely that the significant disruption in performance on target trials was caused by a change in distractor problems. Additionally, as this study controlled for these confounding factors and partial transfer was still demonstrated, this lends support to the results of Speelman and Kirsner, and Speelman et al., indicating that the disruption in performance that they observed could well have been caused by a change in context as they had suggested.

Furthermore, the current study demonstrated partial transfer or a significant disruption between training and transfer phases, despite the same target problems being used in both phases. This finding contradicts the predictions of Anderson (1982, 1993) and Logan (1988), that complete transfer should occur in situations where the problems, and the processes required to solve them, are the same in both training and transfer. Overall, the experiment has supported research by Speelman and Kirsner (2001) and Speelman et al. (2004) by suggesting that the results they demonstrated were most likely a result of contextual change. The results also indicate that some of the transfer predictions of Anderson and Logan are not necessarily correct, and that context might have greater implications on performance of a skill than Anderson or Logan might have expected. Consequently, this study has implications for the theories of Anderson and Logan, by suggesting that aspects of such theories may benefit from some revision or expansion. Such theories could be expanded to recognise that context can affect performance, such as was demonstrated in the current study, where despite there being no change in target problems in training and transfer, performance was disrupted when a change in the surrounding context occurred.
Transfer of Skills

References


