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Accuracy and Variability in Goal Oriented Movements – Decomposing Gender Differences in Children

by

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An essential ability of the motor system is to achieve specified goals with great reliability while the movement trajectories themselves cannot be repeated in an identical fashion. Variability is therefore often different in the outcome and the execution. With this distinction improvements in performance with practice are accompanied by a decrease in variability that can be accounted for by three orthogonal components: "Tolerance", "Noise Reduction", and "Covariation". Central to this decomposition is that performance success is investigated in relation to the dispersion of the variables in execution. This method is applied to a learning study where 12-13-year-old boys and girls practice a virtual skittles task (throwing a ball to hit a target skittle). The results revealed that gender differences in the learning process were present. Boys showed a higher initial level of proficiency in the novel task were significantly faster than girls in finding successful solutions. The variability decomposition reveals that the component tolerance is exploited first in both boys and girls, however much more quickly by boys. This aspect of improvement is followed by noise reduction at an equal rate in both genders. Covariation played a subordinate role. The same sequence of stages was observed in a previous study on adult learners.

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Introduction

In many sports skills and everyday activities actors engage in movements where they try to achieve a desired outcome over successive trials. In sports the examples range from throwing a dart to hit the bull's eye, performing a free throw in basketball, running up to the take-off board for a long jump, to bowling a ball to hit the skittles. Hammering on an anvil is another example from everyday life that has become well known through Bernstein's writings (1935; 1967), but was mentioned even earlier by Woodworth (1899) and Drill (1933) as an exemplary accuracy task. As Bernstein pointed out, the accuracy and relative invariance in the result, hitting the same spot on the anvil, contrast with the observation that the joint angle trajectories of the multi-segmented arm are virtually always different. More recently Todorov and Jordan (2002) stated that it is still an "…especially puzzling aspect of coordination … that behavioral goals are achieved reliably and repeatedly with movements rarely reproducible in their detail". Evidently there are differences between individuals in how such reliability in the outcome is achieved and how the variability in the execution is structured. Such differences may have their origin in different age or gender of the individuals or in their different prior experience. In sports, for instance, it has been a robust and oftentimes replicated observation that male actors almost invariably show higher proficiency in performing goal-oriented throws than female actors. A viable explanation for these differences in skill is that due to sociological factors men tend to have more experience with ball skills. Therefore, it has been of long-standing interest at what age this advantage of boys starts to become prominent. Further, it is of obvious practical interest whether this advantage in ball handling is task specific or whether it can be transferred to novel tasks. A more theoretical interest is whether performance has a different structure of variability and, if so, whether this can point to other sources for these gender differences.

A large number of studies have addressed the issue of gender differences in ball throwing, albeit with inconclusive results (Halverson, Robertson, & Langendorfer, 1982; Hoffmann, Imwold, & Koller, 1983; Nelson, Thomas, & Nelson, 1986; Nelson, Thomas, & Nelson, 1991; Thomas & French, 1985; Thomas, Michael, & Gallagher, 1994). One major drawback in these studies is that they examined throwing tasks, such as the throwing of basketballs or baseballs, where male and female participants were likely to have different degrees of practice before the experiment. It is therefore plausible to explain the reported gender differences with different levels of task-specific experience.

Further, these studies only looked at simple outcome measures, such as hitting the target. In previous studies we argued that for an understanding about the process of learning it is not sufficient to simply measure improvement rates in the task variable (Müller, 2001; Müller & Sternad, 2004). If the goal is to characterise performance changes over practice, more determinants of the task execution have to be examined.

To overcome these drawbacks the present study examined a novel task that was unfamiliar to all participants, both male and female. Second, performance variability was scrutinized using a method developed by Müller and Sternad (2003, 2004). A skittles task was used where participants operate a paddle to throw a virtual ball to hit a target skittle in a virtual workspace. This task has already been used to study learning to hit different target locations in adult participants (Müller, 2001). Additionally, Fieguth and Müller (2001) already compared differences between male and female actors, confirming previous results on more accurate and reliable performance in male participants. Following on from these robust gender differences in ball-accuracy tasks in adults, the present study recruited children at the age of 12-13 years of both genders. The overall hypothesis was that gender differences are already present due to different exposure even at this young age. In more specific terms:

1) These differences are expected to be present as different initial performance levels. Since we present a task, that is new to all participants, this advantage has to be due to an increased level of dexterity that is acquired and transferred from experience with other tasks.
2) Different learning rates are expected for boys and girls, such that lower levels of proficiency show faster rates of increase.
3) Changes in the structure of variability are hypothesized to reveal a similar sequence of stages as found in the performance of adults, although with a different time scale.

In the following we will briefly review the method that decomposes variability into three components (TNC-decomposition). In the same virtual skittles task Müller and Sternad (2004) showed that the three components play different roles throughout the learning process and thereby provide deeper insight into the nature of the change. Based on this, we will report experimental results from a learning study on skittles where we will compare performance of 12-13 year old boys and girls and apply the TNC-decomposition.

The TNC-Decomposition

The method will be described with a schematic data set illustrated in Figure 1. To begin the requisite variables are chosen that form the so-called task space in which the analysis is conducted. For skittles and any other throwing action it holds that the variables of the projectile – angle, velocity, and position at the moment of release – completely determine the trajectory of the projectile. Hence, for a given target location, these three variables completely determine where or whether the projectile will hit the target. Figure 1 shows the so-called task space for the task skittles that is used in the experiment (see description below).

For simplicity the release position, i.e., center of rotation of the body segment, is fixed so that the task space becomes two-dimensional, spanned only by the variables release angle and release velocity. The white band denotes all angle-velocity combinations that hit the target skittle with zero error. Note that the skittle has a 3 cm radius so that there is an error margin. Therefore, the manifold is not a line but a band with a certain thickness. This so-called solution manifold is surrounded by bands of changing grey shades that successively denote increasingly larger deviations from the target. As such, the task space is a gradient field, the height of which is determined by the value of the result variable (deviation from target). The black area denotes angle-velocity combinations that hit the center post and are invalid. In order to illustrate the TNC-decomposition the figure shows a hypothetical sequences of five sets of data, each set with nine symbols denoting nine throws, that illustrate typical changes in performance over a sequence of trials.

First Component: “Tolerance”

The first series of nine throws is indicated by A, the second series of nine throws by B, and so forth. As illustrated, it is not uncommon that the initial set of data is far away from successful performance (in a dark grey area). However, with the first trials the actor explores the task space and soon finds more successful (white) locations, i.e., the combinations of variables that contain zero error solutions. This first stage of exploration is shown by the change from data set A to set B. Here, the mean value of the data set has moved onto the solution manifold.

Given the inevitable variability in a series of executions, another aspect in finding the right location in task space needs to be considered. Locations on the manifold differ in how many successful solutions are adjacent. Note that the width of the bands is different for different locations in task space. For instance, a deviation between 3 to 6 cm from the target skittle, as indicated by one grey shade, allows more combinations of angle and velocity at angles of -90 degrees compared to -150 degrees. In order to reliably achieve a specific result, an actor should aim for such locations that are surrounded by a broad band of successful solutions. Figure 1 illustrates this aspect in the change from data set B to C. Even if the actor is unable to always realize the minimum error solution, the same dispersion of data in C will have a higher probability of success and on average smaller deviations from the target than in B. Such areas of the task space are more “stable” or tolerant with respect to noise in execution. Finding a location in task space with a sufficient safety margin will be referred to as the first component “Tolerance”(*T*). The quantitative contribution of *T* to the result can be extracted (see Müller & Sternad, 2004).

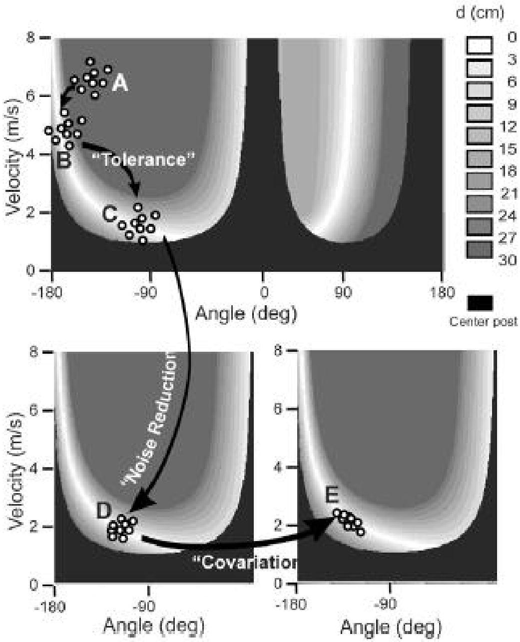

Fig. 1

Task space for the virtual skittles task. For all combinations of angles and velocity of the ball at release the deviation of the minimal distance to the target skittle is calculated. The white area represents combinations that will hit the target skittle (solution manifold), while the different grey shades correspond to increasing distances from the target. The circular dots represents throws or angle-velocity combinatio ns used by a hypothetical subject. This dispersion of data is plotted for five series of nine trials (A, B, C, D, E) each illustrating stages of a hypothetical learning process.

Second Component: “Noise Reduction”

At the end of the 19th century Fullerton and Cattell (1892) and Woodworth (1899) conducted experiments on line drawing, showing that in such accuracy movements a certain degree of variability or noise is inevitable. Although this variability decreases over the course of practice, this “noise” in the execution can never be entirely eliminated. Reduction of “noise” as a consequence of practice is a widely acknowledged component in skill improvement (e.g., Darling & Cooke, 1987; Gottlieb, Corcos, Jaric, & Agarwal, 1989; Higgins & Spaeth, 1972; Hoffmann, 1974; van Galen, Portier, Smits-Engelsman, & Schomaker, 1993; Vorro, 1973; Worringham, 1991, 1993). However, none of these studies provided satisfactory explanation how movements become less “noisy”, and why only to a certain non-zero level. The TNC-decomposition can contribute some insight to this issue by parsing up variability and separate out “random noise” from other sources in the variability. Even if a significant decrease in the overall variability is present, only a part of this may be due to diminished random scatter. Reduction of noise *N* is illustrated in Figure 1 by the change from data set C to D. While the solutions of both data sets remain at the same location on the manifold, the magnitude of their dispersion changes significantly. This change in variability is referred as “Noise Reduction” (*N*).

Third Component: Task-Specific Covariation

A third possibility how variability in the result can decrease during practice is shown in Figure 1 by the difference in the data sets D and E. As can be seen by comparison, the data in set E cluster along with the direction of the solution manifold, they co-vary in contrast to D. In this case variability, or more precisely deviations in the individual processes from the mean, show negative covariation. Deviations in both variables compensate for each other and more accuracy and invariance in the result is achieved. Such covariation was experimentally demonstrated in an early study by Stimpel (1933) who examined repeated forearm throwing actions to a target. The dispersion in the result was smaller than expected from the dispersion measured in the execution variables (angle and velocity at release). Müller and Loosch (1999) replicated Stimpel’s observations using a dart throwing task, similar to Arutyunyan and colleagues who showed for pistol shooting that variations in body and pistol angles compensated for each other (Arutyunyan et al., 1968; Arutyunyan, Gurfinkel, & Mirskii, 1969). More recently this phenomenon was picked up again by Scholz, Schöner and colleagues who discussed this covariation as indication of control and developed a method for extracting this structure from data (Scholz, Danion, Latash, & Schöner, 2002; Scholz & Schöner, 1999; Scholz, Schöner, & Latash, 2000). Müller and Sternad (2003) also developed a method that quantifies this "Covariation" (*C*) between execution variables by a randomization technique. As such this is the third essential component that can reduce variability in the result and improve performance.

The three components are non-overlapping and add to completely account for the quantitative changes in the result. In a learning study with adult performers it was reported that the three components contributed in a differential manner throughout the learning process. Particularly *T* is strongly used at the beginning of the learning the process and loses its importance later in learning when *N* becomes more prominent. The use of *C* is the last component in tuning a skill but its contribution also varies with the task. The present study will apply this decomposition method to a learning study on 12-13 year old children. The objective is to test whether these components can shed light on our understanding of gender differences in a throwing task.

Experiment

Method

Participants. 14 boys and 15 girls, all between 12 and 13 years of age, volunteered to participate in the experiment. Prior to data collection they were instructed about the purpose of the experiment. Their parents gave informed consent according to the regulations of the University of Saarbrücken.

Task and Apparatus.

Participants operated a lever arm in the horizontal plane that was made of light-weight aluminum and was cushioned with foam to provide comfortable support (Figure 2A). The proximal end of the lever arm was poised on a needle bearing to allow free rotation in one angular dimension in the horizontal plane. The lever arm could move a complete 360 deg circle and participants were free to rotate the lever in all directions. The lever movements were displayed on the monitor as schematic paddle movements (Figure 2B). The task was to throw a virtual ball that was also shown on the computer display so that it would hit a target skittle displayed at the far side of the throwing position. This virtual task simulated a ball game called skittles or tether ball. In this (real) task the ball is attached to a long string that is suspended from a long vertical post. The actor grasps the ball away from its hanging position and throws it around the post in a pendular fashion. The target skittle is positioned on the other side of the post and the actor aims to hit the skittle. When this scenario is simulated, the ball trajectory has properties that present a relatively challenging task to the participants. Also, different skittle locations require very different throw and release actions (details about the calculations of the ball trajectories can be found in Müller & Sternad, 2004).

A top-down view of the virtual workspace is presented to the participants (Figure 2B).The work space shown on the monitor corresponded to a 2 x 2 m square around the center post where the origin of the x, y-coordinate system was defined. The participants can see the paddle at the bottom of the display and the ball moving towards the skittle on the display. Participants do not see the angular definitions of the paddle and the ball trajectories. The ball trajectories are only shown here to illustrate their pendular origin and to show the calculation of the deviation from the target. The figure shows three different trajectories due to different release angles and velocities. The trajectories A and B hit the skittle, but trajectory C has a non-zero deviation *d* from the target skittle. The distance to target *d* was calculated as the minimal distance of the trajectory to the target skittle. The center post was displayed as a circular area in the middle of the workspace.

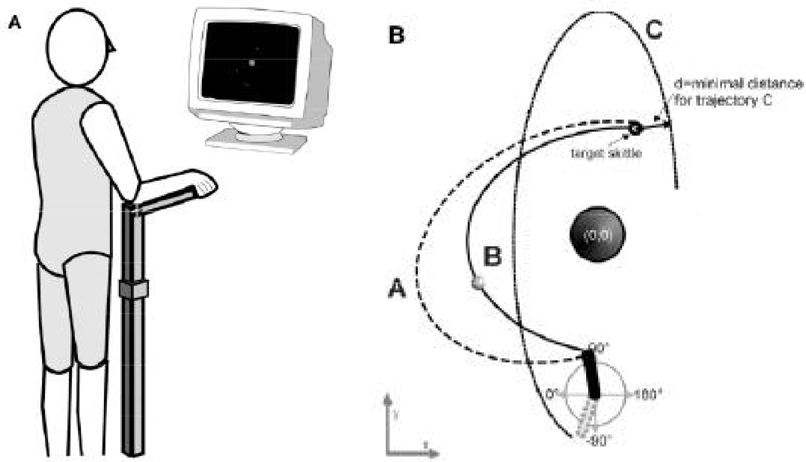

Fig. 2

A: Participant operating the skittles apparatus. B: Top-down view of the skittles task with the x-y coordinate system of the work space. The ball trajectories are projected onto this horizontal plane. The paddle is at 85 deg where the ball of trajectory B is released and travels toward the target skittle. The different ball trajectories are produced by different release angles and velocities. The performance measure for each trial is the minimal distance between the trajectory and the center of the target skittle d. For trajectory C the distance d is shown by an arrow. Trajectories A and B hit the skittle with zero d.

The lever arm was mounted on a vertical post that could be adjusted in height for each participant so that in upright standing position his/her upper arm was vertical and the forearm was horizontal. The standing position of the participant was not prescribed and he/she could stand to the right or left of the vertical post, depending on whether he/she aimed to hit the ball from the left or the right side, or whether the ball was propelled into clockwise or anticlockwise direction around the center post. The displacements of the lever arm were measured by a potentiometer at the axle. At the distal end of the lever arm the participant grasped a spherical wire net. By flexing the index finger he/she could close a contact switch at the tip of the lever. Opening the contact was translated into a release of the ball and the ball's movement was calculated. If the ball touched the center post, it was stopped and the trial was counted as invalid. In the task space, shown in Figure 1, these different anglevelocity pairings of the ball release are mapped to the corresponding distances *d*.

The visual display was presented on a 14-inch monitor that was placed at eye height at 1.2 m distance from the participant. The data from the potentiometer were collected at 700 Hz and used for the estimation of the release parameters that served on-line for the calculation of the ball trajectories. The ball trajectories for the virtual display were calculated by a PC using Turbo-Pascal Software. The delay between data collection and display were within the refresh rate of the computer, which was 13 ms.

Design and Procedure.

Each participant performed two practice sessions on two different days within one week. In each session the participant performed 320 throws. For the data analysis the total of 640 throws was subdivided into 8 blocks consisting of 80 throws each. For a finer-grained analysis the 80 throws were parsed into 8 series of 10 throws each. In Session 1 participants were introduced to the experiment with a standardized instruction. To familiarize themselves with the apparatus they practiced the task with a target position that was not used later in the experiment. In the experiment proper the participants executed a series of 8 throws in a self-initiated sequence but without substantial breaks. On average one throw was performed every 4.5 s. By closing the contact switch the ball was „held“ at the end of the lever and the next throw could be performed at any time.

To provide exact information how close the ball was to the target, the area close to the target skittle was enlarged after each trial, showing both a segment of the ball trajectory and the target skittle. A presentation of one second duration had proven sufficient in pilot trials for participants to take in this error information. Note that while the ball may only "brush" the target skittle, the deviation measure calculated the distance *d* to the center of the skittle. In addition, the participant was given feedback on his/her average performance in terms of an average deviation score after each series of 8 throws. The participants were encouraged to lower their score across the practice sessions. Each session with its 320 throws lasted approximately 30 minutes. None of the participants reported any fatigue with this number and frequency of throws.

Data Reduction and Dependent Measures.

In each trial the variables angular position of the paddle and its velocity were extracted from the sampled data to provide the dependent measures for the execution variables. The associated result variable was the distance *d* to the target skittle. This measure required the calculation of the distance between each point on the ball trajectory and the target and the shortest distance was stored as *d* (see Figure 2B). To show improvements in performance by an increasing value, the measure *d* was defined as a negative value, e.g., an absolute distance of 5 cm will be reported as – 5 cm. For each block of 80 trials the mean of all the distances *d* within that block was calculated to obtain *D*. To quantify the improvement in performance across the 8 blocks, ? *D* was calculated as the difference between the *D* values of Block 1 and Block 8: ? ? *D* = *D8* – *D1*. The contributions of the three factors Tolerance *T*, Noise Reduction *N*, and Covariation *C* to changes in performance were quantified. Changes from Block 1 to Block *i* were calculated as: ? *Ti* = *Ti* –*Ti*–1 (*i* = 2, 3, …8). The contributions were non-overlapping and fully accounted for ? *D*: ? *D* = ? ? *T* + ? *N* + ? *C*. Details about the calculation steps can be found in Müller and Sternad (2003; 2004).

Results

Figure 3 displays the average performance in the outcome measure *D* for both boys and girls. Note that *D* is the average score per block and this figure reflects the overall improvement in the skittles skill across the blocks. It is evident that boys show a significantly better initial score in Block 1 compared to girls. Both groups improved over the 8 blocks of the two sessions. The small discontinuity after Block 4 is due to the fact that there was a day break between the two sessions. The difference between the two groups was primarily found at the beginning of the practice blocks. Starting out with worse performance scores girls showed significantly larger improvements than boys to almost reach the same performance level.

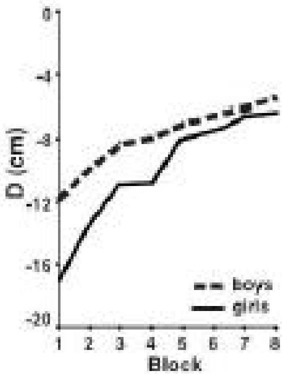

Fig. 3

Performance measure D *(= average distance to target) over 8 blocks of throws shown for both boys and girls.*

Table 1

*Difference between Block 1 and Block 8 in the average distance to the target (*DD*) and the results of an independent-samples* t*-test for both girls and boys. The degrees of freedom are adjusted due to inhomogeneous variances. The changes in the components Tolerance* T*, Noise Reduction* N*, and Covariation* C*, – D*T*, D*N *and D*C*, respectively – , signify the contribution to improved performance.*

Dependent Variable	Girls	Boys	t	df	p
ΔD	10.77	6.22	2.00	18.47	0.03*
ΔT	5.5	0.30	2.47	17.25	0.024
ΔN	5.35	5.87	2.90	18.88	0.775
ΔC	0.26	0.03	0.95	21.03	0.353

This was made explicit by comparing the improvement from Block 1 to Block 8 listed as ?*D* in Table 1 for both groups. Girls showed a group average improvement of 10.77 cm; boys improved their score by 6.22 cm. An independent samples *t*-test reported this difference as significant (Table 1).

Comparing the two sets of *D*-values for each block with one-tailed *t*tests (expecting boys are better than girls), the results confirm that the first three blocks show significant differences but from Block 4 onwards the differences are no longer significant (*df* = 27, *p*-values for all 8 blocks: $p < .13$, .02, .04, .06, .14, .14, .23, .07).

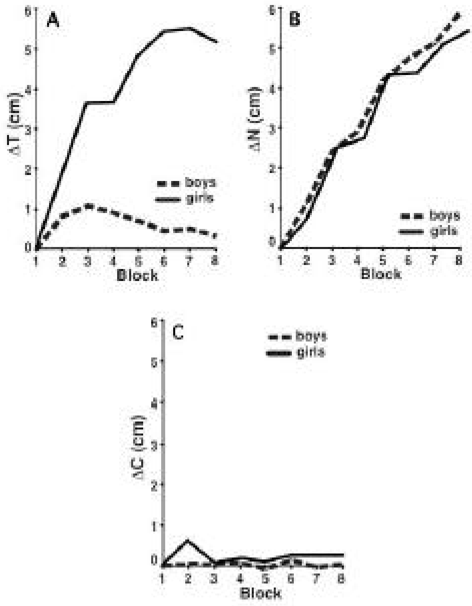

Fig. 4

TNC-components of performance improvement over 8 blocks of trials for boys and girls. The contributions are cumulated from block to block so that the value given at Block i *(*i *= 2, 3, …8) always represent the contribution to the performance difference from Block 1 to Block* i.

Figure 4 shows the contributions of the three components *T*, *N*, and *C* to performance improvements. For each block the cumulative improvement is plotted, for example ? *T* for Block 2 is calculated as the difference between Block 2 and Block 1; ? *T* for Block 3 denotes the difference between Block 3 and Block 1. Comparing the three figures it is evident that the significant differences between boys and girls in *D* are primarily brought about by marked changes in the Δ*T*-component. Statistical results are summarized in Table 1. An independent samples *t*-test compared ? *T*, ? *N*, and ? *C* (calculated for the entire change from Block 1 to Block 8) between boys and girls. This difference was significant only for ? *T*. The component ?*N* also contributed considerably to performance improvement but there was no difference between boys and girls. The component ? *C* was not relevant in this task.

Table 2

Mean valyues of the performance differences ? D from Block 1 to Block 8 for girls and boys and the contributions of the components Tolerance T, Noise Reduction N, and Covariation C after the initial performance values of Block 1 have been partialed out by using them as covariate. The p-values result from a one-way ANOVA with the factor gender.

Dependent Variable	Girls	Boys	p (df = 26)
ΔD	8.20	8.7	0.274
ΔT	3.71	1.87	0.303
ΔN	4.31	6.98	0.140
ΔC	0.17	0.12	0.843

Since the rate of improvement may also be dependent on the general skill level, the observed gender differences in ? *D* and ? *T* could also be an effect of differences in the initial levels of skill. To test this hypothesis, we performed four one-way ANOVAs, one for each of the dependent measures *D, T, N,* and *C*, with gender as the independent variable. The seven differences from Block 1 to Block 8 were entered as the independent variable. Performance *D* in Block 1 was taken as covariate to partial out the effect of different initial level of skill. Figure 5 demonstrates how consideration of the initial performance level changes the interpretation of the data. Figure 5A shows the results of *D* and the three components ? *T*, ?*N*, and ? *C* as reported above with significant differences in ? *D* and ? *T*. Figure 5B showed the results when the initial level *D* was separated out. As the *p*-values show, there are no significant gender differences left. Some trends can be discerned: The larger contribution of ? *T* in girls is diminished but still present. The component ?*N*, on the other hand, shows a tendency to be exploited more by boys.

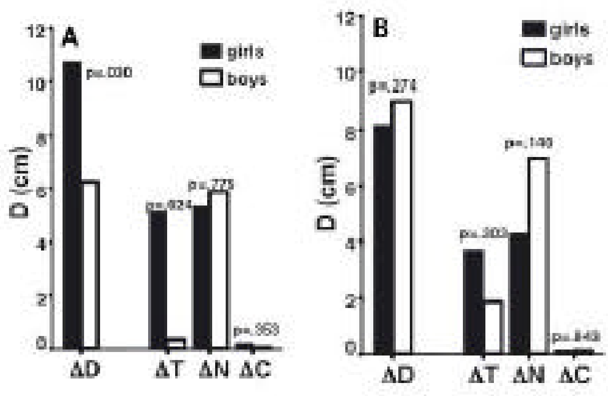

Fig. 5

Improvement in performance ? D *and TNC-components from Block 1 to Block 8 for boys and girls. The* p*-values correspond to the statistical tests described in the text. A: For each dependent measure the columns show the numerical differences in* D. *B: The initial values are eliminated by using performance in Block 1 as covariate.*

In order to better understand these summarized results and why girls use the component *T* to a much larger degree, the first block was analyzed in more detail. Figure 6 shows the first 10 series of throws of Block 1 each consisting of 8 throws. The averages of 8 throws are shown in task space to illustrate the behavior of boys and girls at this first stage of practice in task space. (The series numbers are located exactly above the calculated positions in task space. Additional symbols would have cluttered the illustration too much.) Unlike in the simulated example of Figure 1, the two selected participants chose positive release angles between 0 and 180 degrees. Note that both subparts of the solution manifold, associated with positive and negative release angles, were visited by participants. Figure 6A shows a tightly clustered set of throwing series. However, when following the numbers, it can be discerned that the throws successively approach the whiter regions, i.e., the throws become more accurate. The participant appears to show sensitivity to the gradient of this “field”. Figure 6Bshows a representative girls’ performance. The sequence of throwing series moves from highly unsuccessful series 1 and 2 to better series in the following. This incremental approach to better *D* scores, i.e., lighter grey shades, is what the factor *T* quantifies.

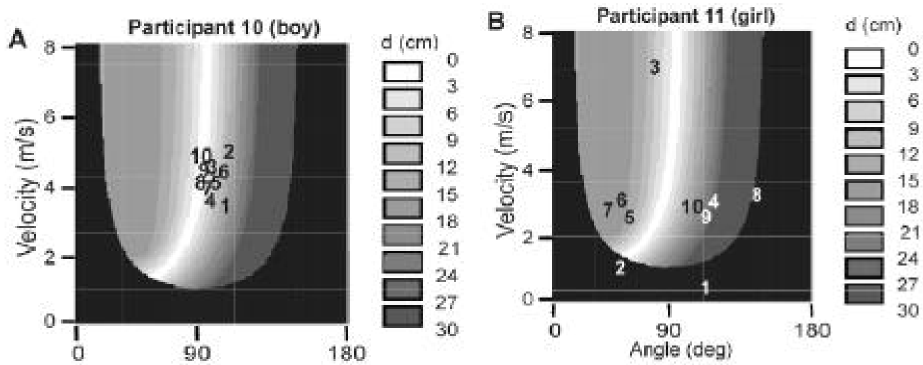

Fig. 6

Throwing results of two representative participants, one girl and one boy, in the 10 series of Block 1. Each number represents the average of 8 throws within one series. Number 1 corresponds to the first series, number 2 to series 2, and so forth. Symbols for the throws have been omitted for clarity.

Discussion

Skilled performance in accuracy tasks such as throwing a ball to a target is characterized by both accurate and reliable performance over a sequence of trials. However, variability across trials is inevitable. Yet, it can have structure and can be different in different aspects of the performance. We specifically distinguished between fluctuations in the result, i.e., hitting the target, and fluctuations in variables that describe the execution of the movement, i.e., release variables. Variability in these two sets of variables can be different and more consistency in the result need not be accompanied by more consistency in the execution. This perspective implies that the task is redundant and more than one combination of executions variables lead to the same result by compensatory covariation. We used a skittles task where a redundancy relation exists between the release variables (two degrees of freedom) that jointly determine the distance to the target (one degree of freedom). This redundancy relation between execution variables and the associated result lies at the heart of the TNC-method that decomposes variability in order to gain more insight into the performance and improvement in skills.

This study applied the TNC-method to data of a learning experiment with the goal to shed light on a long-standing issue of gender differences in skilled performance. A frequent observation in previous studies is that male actors show higher accuracy in throwing than females. One question raised here is whether such gender differences already exist in young children before the sociologically determined greater experience with ball throwing in boys have their full effect. Based on this reasoning we used a virtual skittles task that was novel to all participants where no task-specific experience could be present.

The results from a cohort of 29 children at the age of 12-13 years showed that differences between boys and girls existed, both in the initial performance level and in the rate of improvement. This result is consistent with previous comparisons between adult male and female performance. More specifically, in our study boys were better than girls already in the first 80 trials (Hypothesis 1). This signifies that it is probably prior experience with accuracy throwing tasks that has already effect at this relatively young age. Yet, this experience cannot be task-specific and hence must be transferred from other experience.

Further, consistent with Hypothesis 2, a different learning rate is observed in girls and boys measured across 640 throws. A steep increase shown by girls in the first 4 blocks makes the overall performance *D* come close to the performance of boys. However, this “exponential” rise to the same performance level can be expected as there is a performance ceiling. More pertinent is that this learning curve is also present in boys but it is much faster. This can be concluded from the analysis that extracted the contribution of different initial performance levels. The differences in between boys and girls disappeared shown in the analysis of the different components. Boys show a similar progress when initial differences are partialed out. They are simply faster in attuning to the new task.

The question then is how do boys attune so quickly to a new task and achieve a relatively high level of accuracy? Similar to results by Müller and Sternad (2004), Tolerance *T* was predominant at the beginning of the learning process. A closer look into the first 10 series of practice revealed that a male participant showed a relatively directed traversal through task space towards better solutions. He found the right location ver y quickly and only a reduction of dispersion followed in the next series. The female participant took much longer in exploring the task space and the first 10 series were not enough to locate the best anglevelocity combinations. The exploration of the new task space happened much faster in boys.

With a view to an application of these results into practical contexts, the central question now becomes what kind of experience turns learners into “quick explorers”? Participants with a comparatively higher initial performance level apparently have the capability to transfer prior experience. This leads to a not unknown conclusion that multiple experiences with related tasks should be provided to children at a young age. The more differentiated insight was that such experience helps to improve sensitivity to the gradient in task space.

While it is intuitive that exploring different possibilities to achieve the desired result is a first stage when learning a new task, the TNC-method presents a method that can quantify this often speculated feature. Further, it can separate this explorative component from the other well-known candidate of improvement, namely reduction of noise or scatter. Lastly, even though of not importance in the present task, Covariation has shown in other tasks such as dart throwing to be a major contributor especially at a later stage to fine-tune the performance. In this spirit, the TNC-decomposition can be used to operationalize learning stages.

Acknowledgements

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