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# PROGRESSIVITY OF BASIC ELEMENTS OF THE SLOVENIAN NATIONAL ALPINE SKI SCHOOL

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## SUMMARY

Ski school programmes in different countries are adapted to the local conditions and skiing trends. The aim of the study was to establish the progressivity of the three basic elements of the Slovenian ski school in terms of the duration of individual turns and their phases. Eight participants were recorded as they performed three basic elements of the Slovenian national ski school: wedge curves – E1, turns with a wedge push-off – E2 and basic swinging – E3. According to the ski school, the elements were divided into phases. The results of the computer-aided video analysis showed that in the beginning types of skiing in the same conditions on the same length of terrain, the average durations of turns and the times of comparable initiation and steering phases of the elements shortened on the methodical upward scale (from E1 to E3). The number of turns executed on the same length of terrain from E1 to E3 increased. A larger step in motor task complexity was indicated when a pole plant was included in skiing elements. Further, relatively large differences were observed in time durations among subjects executing the same elements. In conclusion, it can be assessed that the basic elements of the ski school are placed gradually in terms of progressivity in time durations.

**Keywords:** Alpine skiing, basic swinging, kinematics, turn phases, wedge curves

## INTRODUCTION

The development of the Alpine skiing technique has always followed the novelties introduced by competitors. Therefore, the bulk of studies have been conducted in the field of competitive Alpine skiing and have involved an investigation of the skiing technique (Jentschura & Fahrbach, 2004; Federolf et al., 2008; Supej, Kugovnik & Nemec, 2002; Vaverka & Vodičkova, 2012), physical conditioning (Garret & Kirkendal, 2000; Mildner et al., 2012; Müller et al., 2000), equipment (Colbeck, 1994; Coupe, 2008; Ettlinger, Johnson & Shealy, 2006; Federolf et al., 2010; Gustyn, 2012), psychological preparation

(Dosil, 2006; Weinberg & Gould, 2011) and other factors affecting competitive performances to a greater or lesser extent (Heikkinen, 2003; Neumayr et al., 2003). Because the skiing technique of competitive athletes has always affected the skiing technique of the broader population (Petrovič, Šmitek & Žvan, 1984), ski schools have had to adapt to this development with their ski learning techniques and methods (Lešnik & Žvan, 2010).

With the development of the equipment and method for executing turns on the ski edge, Alpine skiing has become ever faster (Shealy, Ettlinger & Johnson, 2005). The new skis, featuring a more pronounced side-cut, facilitate the execution of simple turns on the edge of the skis. However, the development of ski schools has failed to follow this trend (Hildebrandt et al., 2011), which has also been reflected in the number and type of injuries in competitive (Bere et al., 2011) and recreational skiing (Hunter, 1999; Johnson et al., 1997). According to the studies conducted so far, the majority of injuries result from high speed (Veselko & Polajnar, 2008) and other factors (Aschauer et al., 2007; Burtscher et al., 2008; Noé & Paillard, 2005), one of them including skiing knowledge resulting from the national ski school programme (Lešnik & Žvan, 2010).

Ski school programmes in different countries are adapted to the conditions and skiing trends. Nevertheless, there are no substantive differences between ski schools in the most developed skiing countries (Austria, Switzerland, France, Italy etc.) in terms of imparting fundamental skiing knowledge. All of them provide the most important basic instructions about the selection of ski equipment and about the first steps on the snow, whereas later on the complexity of the skiing knowledge and skills increases by adding new contents, which depends on the selection of the terrain and other skiing conditions (e.g. Campell et al., 2000; FISI, 2010; Gamma, 1985; Lešnik & Žvan, 2010; Wörndle, 2007).

There is a paucity of scientific studies related to ski schools and the execution of individual elements. Therefore, with ever higher speeds in skiing (Ruedl et al., 2010) such studies could improve the quality of the learning and consequently raise the level of skiing knowledge in both recreational and competitive sport (Blitzer et al., 1984). This could then enhance the enjoyment derived from skiing, while better knowledge would contribute to greater skiing safety and fewer injuries (Bailey, Boon & Watson, 2009; Goulet et al., 1999; Meyers et al., 2007).

The patterns of motor behaviour in Alpine skiing contain some elements of basic human locomotor movements, although it is a specific motor skill that an individual acquires through the process of directed motor learning (Summers & Anson, 2009). Moreover, the skiing movement occurs in an environment that is at least to some extent unpredictable and the sequences of motor structures are markedly interdependent. The neuromuscular coordination of movement during skiing follows the combined principle of open and closed loop control (Schmidt & Lee, 2005). The latter is specifically important for beginners who learn new elements and for those skiing elements that are executed at a lower relative speed (i.e. the speed of the sequence of motor sub-elements and not necessarily the absolute speed of movement of a skier on the terrain).

To achieve optimal results – this means the rapid learning of motor skills at a minimum risk of injury or other negative side effects in Alpine skiing – the process has to be appropriately structured (Molteni et al., 2012). The principle of progressivity in speed and complexity of movement is an important didactic principle according to which the individual is guided until they carry out a skiing element optimally (Winter, 2009). What is meant by progressivity in the speed of learning of Alpine skiing is the time frame in which a motor task(s) must be implemented. The number of motor tasks that are performed can be high or low (Kawato & Gomi, 1992; Shumway-Cook & Woollacott, 2000) and the skier must execute them within a specific time period. Alpine skiing involves the linking of different ski turns in given conditions. Every ski turn consists of individual inter-related phases (Müller, 1994). Namely, it is a series of necessary motor tasks that can be kinematically defined (Brodie, Walmsley & Page, 2008; Nachbauer et al., 1996). Practical experience shows that ski turns cannot be learnt in one step, but that different methodological approaches and paths to learning to ski are required and/or an Alpine ski school. They are based on the gradual and progressive development of the elements of skiing motor skills.

## PURPOSE

Therefore, the basic aim of the study is to establish the progressivity of the three basic elements of the Slovenian ski school in terms of the duration of individual turns and their phases. Based on the established time parameters of complete execution (synthetically) and its individual phases (analytically), we will try to establish whether the elements of the Slovenian ski school are structured gradually in terms of their time parameters and complexity.

## PROCEDURES

Eight elite Alpine skiing demonstrators, members of the national Slovenian Demo Team (mean age = 27.14 years, SD = 1.35 years; mean height = 176.28 cm, SD = 7.45 cm; mean body weight = 71.57 kg, SD = 9.16 kg), participated in the study and gave their written informed consent. The study was conducted in accordance with the Helsinki Declaration and was approved by the regional Ethics Committee at the Faculty of Sport, University of Ljubljana, Slovenia.

Each participant performed three basic elements of the Slovenian national ski school: wedge curves – E1 (Figure 1), turns with a wedge push-off – E2 (Figure 2) and basic swinging – E3 (Figure 3) and was measured using a 25-Hz high-definition camcorder (Sony HC-7, Sony Corp., Japan) from the start to finish of each element. In order to increase the frequency of the measurement, the interlaced high-definition video recordings were first transformed to a 50-Hz format by a field-to-frame procedure involving two open-source video-editing software packages (Avi Synth 2.5.8, Virtualdub 1.9.11).

The measured ski school elements were divided into turn phases according to the motor tasks needed as described earlier. According to the official Slovenian ski school (Lešnik & Žvan, 2010), the elements E1, E2 and E3 can be divided into several individual development phases:

Four phases of element E1:

- the gentle traversing (GT) phase in a high body position with a parallel ski position (preparatory phase);
- the initiation phase (IP) with wedge positioning and the transition from the parallel ski position to snowploughing (wedging) and body movement from a higher to a lower position;
- the steering phase (SP) with the performance of a wedge curve;
- the transition to gentle traversing (TGT) with body movement from a lower to a higher position (preparatory phase).

Two phases of element E2:

- the initiation phase (IP) with a push-off in the direction of a new turn and wedging (snowploughing); body movement from a lower to a higher position;
- the steering phase (SP) with the performance of a parallel turn with lowering of the body.

Two phases of element E3:

- the initiation phase (IP) with a push-off and pole planting in a parallel ski position and the transition to a higher body position;
- the steering phase (SP) with the performance of a parallel turn with lowering of the body.

For each skier and each element at least eight turns were recorded on a gentle and wide course as required for basic ski school teaching (Lešnik & Žvan, 2010). The snow conditions were close to ideal with natural and groomed snow. The weather was sunny which enabled impeccable visibility and the air temperature was around −6 °C.

The durations of the turns and the turn phases were derived from the computer-aided video analysis performed by an expert panel consisting of two Alpine skiing researchers and two professional ski instructors, members of the elite Demo team group. First, the

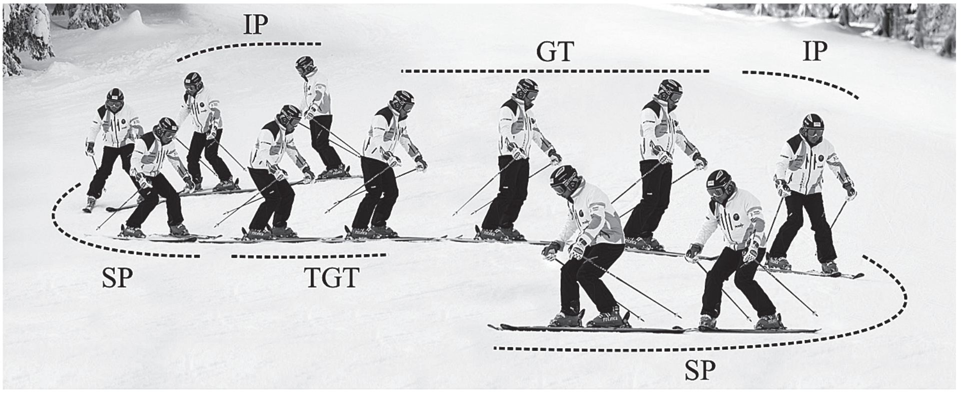


**Figure 1.** E1 – Wedge curves with four turn phases

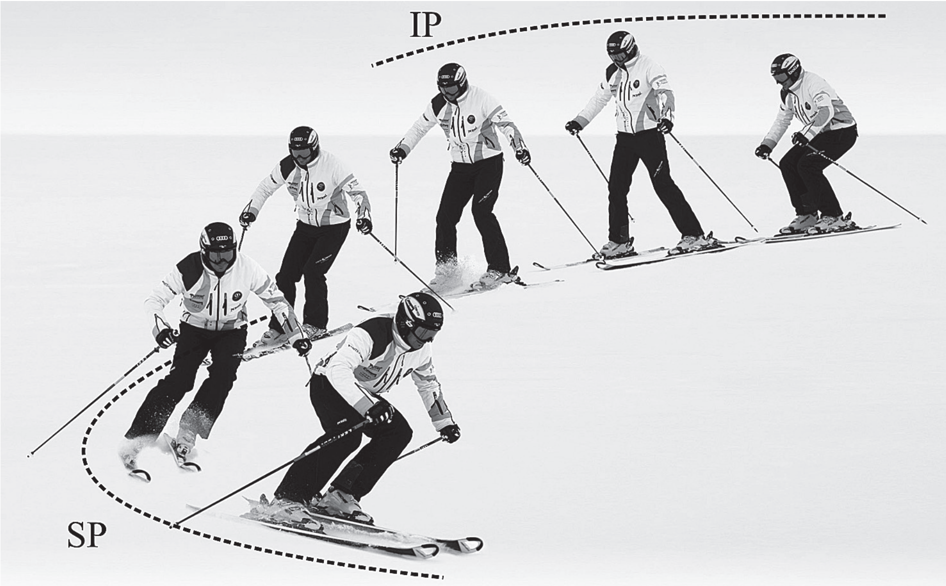


**Figure 2.** E2 – Turns with a wedge push-off with two turn phases

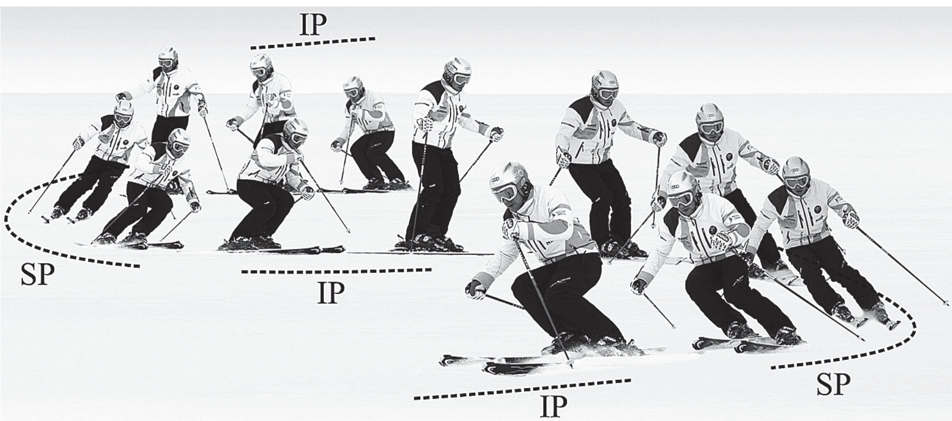


**Figure 3.** E3 – Basic swinging with two turn phases

panel together approved the characterisation of the turn phases for each element described above. Thereafter, they independently analysed the durations of the phases for each skier and each element. After that analysis, the four evaluators reviewed the video together and agreed on their judgements. Their initial judgements before the agreement differed by a maximum of two video frames (0.04 s).

## Data analysis

Basic distributional parameters (mean, standard deviation) were computed for each element, turn phase and subject. Differences in the mean duration of elements and their phases were tested using the linear mixed-effect model in the R 2.14 (http://r-project.org) programming environment with the *nlme* library and *REML* (restricted maximum-likelihood) method used to construct the model. Differences between subjects as fixed effects were tested with the *lm* library.

## RESULTS

Figure 4 shows the average times (mean) and standard deviations in the durations of complete turns executed by all study subjects by turns (1 to 10) of individual skiing elements (E1, E2 and E3). The presented average times (mean) and standard deviations (SD) show that the turns from 1 to 10 in elements E1, E2 and E3 were on average executed by study subjects over different periods of time ($p < 0.001$). The average duration of the turns of the E1 element (mean = 5.61 s; SD = 0.69 s) was almost twice the average duration of the turns of the E2 element (mean = 2.93 s; SD = 0.46 s), whereas the average duration of the turns of the E3 element was the shortest (mean = 1.96 s; SD = 0.26 s). The variation coefficient (KV) in the E1 element was the smallest (KV = 12%), in the E2 element the largest (KV = 16%), whereas in the E3 element it was KV = 13%.

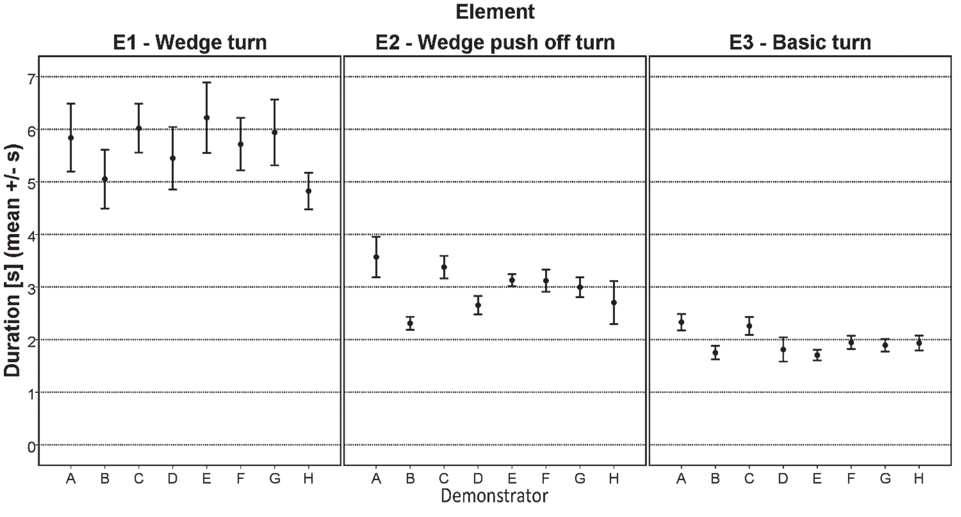


**Figure 4.** The average times (mean) and standard deviations in the duration of complete turns of all study subjects, by turns of selected elements of the ski school

Figure 5 shows the averages (mean) and standard deviations (SD) in the duration of all captured turns of individual elements of ski school, by study subjects (A to H). The differences between the study subjects are statistically significant ($p < 0.001$) but smaller than the differences between the turns (elements), as the former explain only 3.5% and the latter 91% of the variance of the duration of turns. The average values of the duration of all performed turns (mean) by study subjects (A to H) differ the most in the E1 element (range: 4.83–6.22 s). E1 also revealed the highest standard deviations (from 0.35 to 0.65 s). The element E1 was executed the fastest by study subject H (mean = 4.83 s; SD = 0.35 s), and the slowest by study subject E (mean = 6.22 s; SD = 0.67 s).

The means of the duration of all turns performed by the study subjects (A to H) were half of that in the E2 element (range: 2.30–3.52 s) compared to the E1 element. This element also shows smaller standard deviations (from 0.11 s to 0.44 s). It is evident from the results that element E2 was executed the fastest by study subject B (mean = 2.30 s; SD = 0.12 s), and the slowest by study subject A (mean = 3.52 s; SD = 0.38 s).

The study subjects executed the E3 turns in an even shorter average time (from 1.72 s to 2.36 s), and the standard deviations were the smallest for this element (from 0.08 to 0.24 s). It is evident from the results that element E3 was executed the fastest by study subject E (mean = 1.72 s; SD = 0.08 s) and the slowest by study subject A (mean = 2.36 s; SD = 0.14 s).

From the elements E1 to E3, by study subject, the average values of all executed turns and also the standard deviations decrease. The coefficient of variation decreases from the E1 element (KV = 9.7%), through E2 (KV = 7.9%) to E3 (KV = 6.9%).

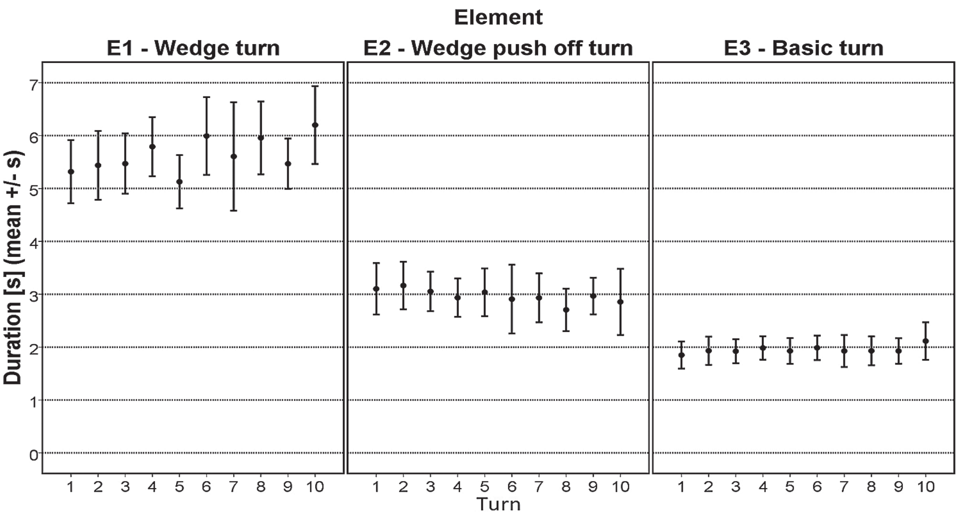


**Figure 5.** The means and standard deviations in the duration of all captured turns of individual elements of ski school, by study subjects

**Table 1.** Basic statistical parameters of the duration of each individual turn by phase of elements E1, E2 and E3

| Task | Turn Phase | | Turn | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | all |
| E1 | GT1 | mean (SD) | 1.07 (.61) | 1.17 (.49) | 1.00 (.43) | 1.15 (.44) | .91 (.35) | 1.21 (.56) | 1.18 (.49) | 1.32 (.45) | 1.12 (.39) | 1.28 (.47) | 1.13 (.46) |
| | | KV % | 57% | 42% | 43% | 39% | 39% | 47% | 41% | 34% | 34% | 37% | 41% |
| | IP1 | mean (SD) | .76 (.32) | .96 (.27) | 1.02 (.54) | 1.17 (.24) | .96 (.30) | 1.22 (.19) | .89 (.50) | 1.10 (.33) | 1.04 (.33) | 1.28 (.17) | 1.03 (.35) |
| | | KV % | 42% | 28% | 53% | 20% | 31% | 16% | 56% | 30% | 32% | 14% | 34% |
| | SP1 | mean (SD) | 2.41 (.32) | 2.49 (.36) | 2.45 (.42) | 2.65 (.39) | 2.25 (.30) | 2.69 (.46) | 2.41 (.34) | 2.54 (.59) | 2.11 (.41) | 2.64 (.21) | 2.47 (.40) |
| | | KV % | 13% | 14% | 17% | 15% | 13% | 17% | 14% | 23% | 20% | 8% | 16% |
| | TGT1 | mean (SD) | 1.08 (.30) | .82 (.18) | 1.00 (.16) | .82 (.19) | 1.01 (.20) | .88 (.12) | 1.12 (.35) | 1.00 (.25) | 1.20 (.31) | 1.01 (.15) | 0.98 (.25) |
| | | KV % | 28% | 22% | 17% | 23% | 20% | 14% | 31% | 25% | 26% | 15% | 25% |
| E2 | IP2 | mean (SD) | .79 (.25) | .85 (.31) | .80 (.09) | .78 (.10) | .85 (.17) | .87 (.38) | .84 (.13) | .79 (.08) | .86 (.11) | .78 (.10) | 0.82 (.20) |
| | | KV % | 31% | 37% | 11% | 13% | 20% | 44% | 15% | 11% | 13% | 12% | 24% |
| | SP2 | mean (SD) | 2.32 (.35) | 2.32 (.39) | 2.26 (.40) | 2.16 (.32) | 2.19 (.38) | 2.04 (.36) | 2.10 (.38) | 1.92 (.33) | 2.11 (.27) | 2.08 (.55) | 2.16 (.37) |
| | | KV % | 15% | 17% | 18% | 15% | 17% | 18% | 18% | 17% | 13% | 26% | 17% |
| E3 | IP3 | mean (SD) | .59 (.11) | .59 (.08) | .58 (.05) | .59 (.10) | .58 (.04) | .64 (.06) | .59 (.07) | .60 (.06) | .57 (.06) | .66 (.10) | 0.60 (.08) |
| | | KV % | 19% | 14% | 8% | 16% | 7% | 9% | 11% | 10% | 11% | 15% | 13% |
| | SP3 | mean (SD) | 1.26 (.19) | 1.35 (.20) | 1.34 (.20) | 1.40 (.18) | 1.35 (.22) | 1.35 (.18) | 1.34 (.26) | 1.33 (.24) | 1.36 (.21) | 1.46 (.31) | 1.35 (.21) |
| | | KV % | 15% | 15% | 15% | 13% | 16% | 14% | 19% | 18% | 15% | 21% | 16% |

Legend: E1 – Wedge curves with four turn phases; E2 – Turns with a wedge push-off with two turn phases; E3 – Basic swinging with two turn phases; GT – gentle traversing phase; IP – Initiation phase; SP – Steering phase; mean – Mean of results; SD – Standard deviation; KV – Coefficient of variation

Table 1 shows basic statistical parameters of the duration of each turn by individual phases (GT, IP, SP and TGT) of the E1, E2 and E3 elements. In contrast to the other two elements, the E1 element also has the GT1 and TGT1 phases. The average duration of the GT1 phase was approximately 1 second. On average, the subjects executed the GT1 phase the fastest in the 5th turn (mean = 0.91 s; SD = 0.35 s), and the slowest in the 8th turn (mean = 1.32 s; SD = 0.45 s). In this phase, the coefficient of variation (KV) was the largest in the first turn (57%) and the smallest in the 10th turn (37%). In the IP1 phase, the duration was shorter on average than in the GT1 phase. The latter is the shortest in the first turn (mean = 0.76 s) and the longest in the last turn (mean = 1.28 s). The highest coefficient of variation (KV) of the IP1 phase was in the 7th turn (KV = 56%) and 3rd turn (KV = 53%), whereas the smallest was in the 10th turn (KV = 14%) and 6th turn (KV = 16%). The average duration of the SP1 phase was quite a lot longer than the other three phases in E1. On average, the results revolve around 2.5 s; however, the subjects executed the SP1 phase for the longest time in the 6th turn (mean = 2.69 s; SD = 0.46 s) and for the shortest time in the 9th turn (mean = 2.11 s; SD = 0.41 s). The coefficients of variation (KV) in the SP1 phase were relatively low in all turns (from 13 to 23%). The subjects executed the last phase on average for about one second (mean from 0.82 to 1.20 s; SD = 0.18 to 0.31 s).

In the E2 element, the average duration of the IP2 phase was less than a second. The subjects executed the IP2 phase the fastest in the 4th and 10th turns (mean = 0.78 s; SD = 0.10 s), whereas in all other turns the average duration of the phase was longer, with the longest being the 6th turn (mean = 0.87 s; SD = 0.38 s). The highest KV (44%) was calculated in the 6th turn. The average duration of the SP2 phase was more than twice as long as the IP2 phase. On average, the results exceed 2 s. The subjects executed the SP2 phase for the longest time in the 1st turn (mean = 2.32 s; SD = 0.35 s), while the shortest average time for the SP2 phase of this element was recorded in the 8th turn (mean = 1.92 s; SD = 0.33 s).

In the E3 element, the average duration of the IP3 phase was the shortest, ranging from 0.58 to 0.66 s. The calculated coefficients of variation (KV) in the IP3 phase ranged from 4 to 11%. The average duration of the SP3 phase was longer than the IP3 phase. On average, the results revolve around 1.3 s. The subjects executed the SP3 phase for the longest time in the 10th turn (mean = 1.46 s; SD = 0.31 s), with the shortest average time for the SP phase of this element being recorded in the 1st turn (mean = 1.26 s; SD = 0.19 s).

Differences in the duration of analogue phases of different elements (IP1, IP2 and IP3; SP1, SP2 and SP3) were tested using linear mixed-effects models with phases and turns as fixed factors and subjects as a random factor. In both cases (IP and SP), the differences between the phases were found to be highly significant ($p < 0.001$).

**Table 2.** Basic statistical parameters of the duration of the phases of turns in all three elements, by study subjects (A to H)

| Task | Turn Phase | | Study subjects (A–H) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | A | B | C | D | E | F | G | H |
| **E1** | | N1 | 8 | 9 | 10 | 8 | 6 | 11 | 10 | 10 |
| | GT1 | mean (SD) | 1.23 (.31) | 1.19 (.27) | 1.25 (.39) | 0.62 (.16) | 0.99 (.38) | 1.49 (.32) | 1.56 (.43) | 0.59 (.19) |
| | | KV% | 25% | 23% | 31% | 26% | 39% | 22% | 28% | 32% |
| | IP1 | mean (SD) | 1.31 (.25) | 0.79 (.17) | 1.28 (.32) | 1.11 (.32) | 1.02 (.21) | 1.03 (.40) | 1.00 (.29) | 0.72 (.35) |
| | | KV% | 19% | 22% | 25% | 29% | 21% | 39% | 29% | 49% |
| | SP1 | mean (SD) | 2.31 (.17) | 2.16 (.20) | 2.55 (.30) | 2.59 (.59) | 3.23 (.38) | 2.29 (.30) | 2.37 (.23) | 2.51 (.22) |
| | | KV% | 7% | 9% | 12% | 23% | 12% | 13% | 10% | 9% |
| | TGT1 | mean (SD) | 0.99 (.33) | 0.91 (.33) | 0.95 (.11) | 1.13 (.19) | 0.98 (.24) | 0.91 (.21) | 1.02 (.28) | 1.00 (.23) |
| | | KV% | 33% | 36% | 12% | 17% | 24% | 23% | 28% | 23% |
| **E2** | | N2 | 9 | 13 | 9 | 10 | 7 | 10 | 10 | 8 |
| | IP2 | mean (SD) | 1.14 (.37) | 0.73 (.07) | 0.86 (.17) | 0.80 (.08) | 0.67 (.05) | 0.78 (.07) | 0.80 (.06) | 0.75 (.08) |
| | | KV% | 32% | 9% | 20% | 10% | 7% | 9% | 8% | 11% |
| | SP2 | mean (SD) | 2.43 (.11) | 1.58 (.12) | 2.52 (.17) | 1.85 (.16) | 2.46 (.14) | 2.34 (.21) | 2.20 (.17) | 1.96 (.40) |
| | | KV% | 5% | 7% | 7% | 8% | 6% | 9% | 8% | 20% |
| **E3** | IP3 | N3 | 13 | 16 | 11 | 13 | 10 | 13 | 12 | 10 |
| | | mean (SD) | 0.67 (.09) | 0.56 (.08) | 0.66 (.05) | 0.56 (.05) | 0.57 (.04) | 0.61 (.08) | 0.62 (.07) | 0.60 (.09) |
| | | KV% | 13% | 15% | 8% | 9% | 8% | 13% | 12% | 15% |
| | SP3 | mean (SD) | 1.66 (.09) | 1.19 (.12) | 1.60 (.15) | 1.26 (.23) | 1.14 (.08) | 1.34 (.11) | 1.28 (.08) | 1.34 (.09) |
| | | KV% | 6% | 10% | 10% | 18% | 7% | 9% | 6% | 7% |

Legend: E1 – Wedge curves with four turn phases; E2 – Turns with a wedge push-off with two turn phases; E3 – Basic swinging with two turn phases; GT – gentle traversing phase; IP – Initiation phase; SP – Steering phase; mean – Mean of results; SD – Standard deviation; KV – Coefficient of variation; N – number of turns

Table 2 shows the number of executed turns and the average duration (mean), standard deviations and coefficients of variation of all executed phases of all captured turns of elements E1, E2 and E3, by study subjects from A to H. The subjects executed a different number of turns on the same length of the terrain (with element E1 from 6 to 11 turns, E2 from 7 to 13 turns and E3 from 10 to 16 turns). In terms of executed turns within an individual element, subject E stands out from the other subjects with a low number of turns: 6 (in E1), 7 (E2) and 10 (E3). The highest number of turns in all three elements was executed by subject B: 9 (in E1), 13 (in E2) and 16 (in E3).

In element E1 the subjects executed the GT1 phase for about 1.3 s on average. The most outstanding examples included subject G who executed this phase for the longest time (mean = 1.56 s, SD = 0.43 s) and subject H who needed the least time to execute this phase (mean = 0.59 s, SD = 0.19 s). The highest coefficient of variation (KV) in the GT1 phase was that of subject E (KV = 39%) and the smallest of subject F (KV = 22%). The average time of execution of the IP1 phase was about 1 second, whereas the phase was executed the fastest by subjects H (mean = 0.72 s, SD = 0.35 s) and B (mean = 0.79 s, SD = 0.17 s). Subjects A (mean = 1.31 s, SD = 0.25 s) and C (mean = 1.28 s, SD = 0.32 s) needed the most time to execute the IP1 phase in this element. The coefficients of variation (KV) of this phase range in most subjects from 19 to 29%; subjects H (KV = 49%) and F (KV = 39%) stand out. Compared to other phases of the E1 element, the SP1 phase was at least 1 second longer for all subjects. On average, the subjects executed it for 2.3 seconds; the highest value was that of subject E (mean = 3.23 s; SD = 0.38 s) and the lowest of subject A (mean = 2.16 s; SD = 0.20 s). The coefficients of variation (KV) of this phase were below 13% for most subjects, except for subject D (KV = 23%). For most subjects, last phase of element E1 (TGT1) lasted on average about 1 second (from 0.91 to 1.13 s) and the standard deviations ranged from 0.22 to 0.19 s. The lowest coefficient of variation (KV) in the TGT1 phase was that of subject C (KV = 12%) and the highest of subject B (KV = 36%).

In the E2 element most subjects executed the IP2 phase in less than a second. The most outstanding examples included subject A who took the longest time to execute this phase (mean = 1.14 s, SD = 0.37 s) and subject E who needed the least time to complete this phase (mean = 0.67 s, SD = 0.05 s). The coefficients of variation (KV) in execution of the E2 phase by the subjects were mostly below 11%; the lowest KV was that of subject E (KV = 5%) and the highest of subject A (KV = 32%). Compared to the IP2 phase, the SP2 phase was at least 1 second longer for all subjects. On average, the subjects executed it for about 2 seconds; the time range was from (mean = 1.58 s; SD = 0.12 s) for subject B to (mean = 2.52 s; SD = 0.17 s) for subject C. The calculated coefficients of variation (KV) of this phase were below 9% for most subjects, except for subject H (KV = 20%).

The E3 element, compared to the E1 and E2 elements, lasted on average for the least time with all study subjects. This applies to the IP3 and SP3 phases. The average time of execution of the IP3 phase was slightly more than 0.5 second, whereas the phase was executed the fastest by subjects B (mean = 0.56 s, SD = 0.08 s) and D (mean = 0.56 s, SD = 0.05 s) and the slowest by subject A (mean = 0.67 s, SD = 0.09 s). The coefficients of variation of the IP3 phase were low for the study subjects, ranging from 8 to 15%. The subjects executed the SP3 phase a little longer, namely in about 1.3 seconds. Subject E (mean = 1.14 s, SD = 0.08 s) needed the least time to execute the SP3 phase, and subject

A the most (mean = 1.66 s, SD = 0.09 s). The calculated coefficients of variation (KV) of the SP3 phase were below 10%, except for subject D (KV = 18%).

## DISCUSSION

The main results of the study showed that in the beginning types of skiing in the same conditions on the same length of terrain, the average durations of turns and the times of comparable phases (IP and SP) of the elements of the ski school shortened on the methodical upward scale (from E1 to E3). On the other hand, the number of turns executed on the same length of terrain from E1 to E3 increased. Therefore, we can assess that the elements of the ski school are, in terms of progressivity in speed, gradually placed as a consequence of the hierarchically set initial elements of the ski school (Lešnik & Žvan, 2010). The reasons lie in the basic characteristics of Alpine skiing that are defined by speed, timeliness, accuracy, rhythmic and softness of skiing (Petrovič, Šmitek & Žvan, 1984). Of all the above skiing characteristics, the timeliness and rhythmic ones are time-limited in each individual turn, whereas the speed of sliding is by all means a basic condition for carrying out an individual element in the hierarchy of elements of each ski school.

If the results are discussed using the methodical scale of the ski school in an upward direction, it can be established that all phases of the turn (GT, IP, SP, TGT) in E1 are executed slower than in comparable phases (IP, SP) of hierarchically more demanding elements (E2 and E3). The reason for this lies in the speed which has to be adjusted to skiers with a lower level of knowledge. This can be achieved with the appropriate completion/closing of turns. Due to the longer or shorter phase of gentle traversing (GT) in the E1 element, one cannot speak about the rhythm of skiing (the turns are unrelated in terms of movement). To implement movement in E1, accuracy, timeliness and softness are less important. It has been shown that in the GT phase the differences between the subjects in terms of duration are the largest as a consequence of longer or shorter traversing. Practically speaking, skiing teachers – the subjects of this study are all skiing teachers – must adjust the time of traversing and preparation for the execution to the abilities of the learners, whereas the level of knowledge of the learners that the subjects should teach was not prescribed. It is also interesting that the time of traversing (GT) was longer especially in the first turns when the speed of skiing was probably lower.

The E2 element involves upgrading of the learnt motor information where, compared to the E1 element, the speed of skiing is slightly higher (Žvan, Lešnik & Supej, 2012), whereas the motor tasks in subsequent phases pass from one to another more directly. Due to a faster skiing rhythm (shorter times) the mutually comparable phases (IP and SP) in E2 are shorter than in E1 and the movement is more complex. This involves the simultaneous execution of several necessary movements in the same or even a shorter time period with their known consequences (Christina & Rose, 1985; Danthir et al., 2005; Deary, Der, & Ford, 2001, Endsley, 2006; Memmert, Simons, & Grimme, 2009); in the case of our study these were push-off, wedge push-off of the upper ski, pole planting etc. The complexity of the movement has been discussed on the basis of studies of special psychological abilities (Knudson, 2013), conductivity of the nervous system (Hertensein & Weiss, 2011) and intelligence (Agrawal & Kumar, 1993; Jensen & Munro, 1979). These are all interconnected sets of activities that, given the desired way of movement and external stimuli, can appear in a more simple or complex form (Favilla, 2002).

Likewise, the E3 element involves upgrading of the acquired motor knowledge from E2. The speed of skiing increases (Žvan, Lešnik & Supej, 2012), while at the same time our study ascertained that the rhythm of skiing or duration of turns and their phases increases too. It should also be emphasised that the skiers in E3 execute the entire turn with a parallel ski position which increases the need for knowledge to manage the skis in the IP phase when the skis must turn in the direction towards the fall line (Lešnik & Žvan, 2010). Due to the above, there is a need for a slightly higher speed of skiing and coordinated pole planting that increases the need for timeliness and accuracy (Petrovič, Šmitek & Žvan, 1984).

The need for coordinated pole planting with a parallel ski position is so great that in the methodology of learning to ski the E2 element can be executed – as an interim exercise from E2 to E3 – with the planting of the pole (Figure 6). This one belongs to the IP phase which increases the complexity of movement, nevertheless the exercise is helpful in ensuring a smoother transition to E3 which represents the most basic way of skiing in a parallel ski position through all phases of the turn.

The speed of executing simple and complex movements in skiing increases on the methodical scale, yet reactions to a large number of (un)expected stimuli during skiing also occur. In this context, we are not only referring to a series of specific reflex reactions but, in such situations, the reaction depends on the development of cognitive functions, the age of the subject and other factors (Light & Spirduso, 1990). During skiing there is an uninterrupted flow of different external stimuli and/or an appropriate selection of reactions to the environment which depends on the already acquired skiing knowledge as well as the general intelligence of the subject. This is related to a person's ability to solve problems and is also an indicator of the successfulness of that person when faced with a new situation. The success of introducing the desired movement is not only influenced by the selection of appropriate motor programmes but also by the degree of control and

**Figure 6.** Turns with a wedge push-off with a pole plant as a pre-exercise for basic turning

level of concentration and, consequently, also the number of incorrect movements. Studies confirm the fact that, by increasing the number of concurrent movements, the time of reacting to a stimulus grows. This is particularly true for subjects who are still learning a complex movement (Henry & Rogers, 1960).

The main limitation of the study is that the measurements were performed with a computer aided video-analysis where the accuracy of the definition of phases and the beginnings and ends of the turns is limited by the frequency of capturing and defined through visual perception. For the purpose of ensuring the greatest measurement accuracy, the expert panel was composed of people with different skiing and scientific knowledge. Each member of the expert panel conducted the analysis of the phases individually, and then the members harmonised their findings. Nevertheless, the assessed accuracy of the determination of the times of the turns and phases is better than ±0.04 s, yet lower than could be achieved with the use of determination of phases through measurements of 3D kinematics (Müller et al., 1998; Supej, Kugovnik & Nemec, 2003) or through measurements of the ground reaction forces (Vaverka & Vodičkova, 2012).

In conclusion, to our knowledge this study is the first to deal with the complexity of movement of the elements of the Alpine ski school and their methodical progressivity. The study focused on the initial elements of skiing that represent the pillar of the Slovenian national skiing school. Nevertheless, the methodological progression of these core elements of other national alpine ski schools are similar, therefore the findings of this study might be possible to generalize. We are aware that in the future it would be reasonable to verify whether the complexity of movement also intensifies in a similar way in the continuous elements of the ski school or whether this only involves aggravating circumstances that manifest themselves in higher ground reaction forces and the related need for better balance, higher speed and additional time limitation. Since skiing speed, as indicated by the measurement, is an important factor in the methodological scale, it would be reasonable to conduct measurements that can verify accurately how the speed changes with the elements of the ski school as well as how the selection of the terrain, the snow and other conditions in which the skier learns to ski affect the execution of elements of the ski school. It would be worth studying more accurately the complexity of movement during skiing and the differences between individual movements in the same phases of various elements of the ski school.

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## PROGRESIVITA ZÁKLADNÍCH ELEMENTŮ SLOVINSKÉ NÁRODNÍ ŠKOLY ALPSKÉHO LYŽOVÁNÍ

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SOUHRN

Programy lyžařských škol v různých zemích jsou přizpůsobeny místním podmínkám a lyžařským trendům. Cílem této studie bylo stanovit progresivitu tří základních prvků slovinské lyžařské školy, pokud jde o dobu trvání jednotlivých zatočení a jejich fází. U osmi účastníků bylo zaznamenáno, jak provádějí tři základní prvky ze slovinské národní lyžařské školy: E1 – oblouk z pluhu; E2 – oblouk z přívratu vyšší lyží E3 – paralelní oblouk. Podle lyžařské školy byly prvky rozděleny do fází. Výsledky počítačové video- analýzy ukázaly, že na začátku lyžování za stejných podmínek a stejné délky terénu, je průměrná doba zatáčení a časů srovnatelného zahájení a řízení fází, jsou tyto prvky dle metodické vzestupné škály zkráceny (od E1 po E3). Počet zatočení provedených na stejné délce terénu se zvýšil; od E1 po E3. Delší pokrok byl v motorické komplexnosti úlohy, indikován při jejich začleněného do lyžařských prvků. Poměrně velké rozdíly mezi subjekty, které prováděli stejné prvky, byly zaznamenány v době jejich trvání. Na závěr lze usuzovat, že základní prvky lyžařské školy jsou postupně z hlediska progresivity podle času jejich trvání, implementovány.

**Klíčová slova:** Alpské lyžování, kinematika, otočné fáze, klínové křivky

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